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Palynological analysis of Tiger and Trinity Shoals, Louisiana continental shelf

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PALYNOLOGICAL ANALYSIS OF TIGER AND TRINITY SHOALS, LOUISIANA CONTINENTAL SHELF

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ABSTRACT

Forty sediment samples taken from twenty-six vibracores collected from Holocene shoals (Tiger and Trinity) were processed for palynomorphs and analyzed to characterize the terrestrial and marine paleo-environments of Southern Louisiana at the time of deposition of each shoal. Abundant and diverse pollen assemblages were recovered while marine microplankton were sparse (<2% relative abundance). Pollen species were grouped by plants of similar environmental significances including arboreal, non-arboreal, aquatic, and shrub categories. Palynological signals were compared in detail between each core, as well as along strike and dip transects, to help determine whether or not these shoals were deposited coevally or in distinct depositional cycles.

Evidence shows that Tiger and Trinity Shoals carry remarkably similar palynological profiles, indicating that sediments of these shoals are from the same source, and that deposition extended over an interval of time such that climate change was not sufficient enough to alter the vegetation response (hence palynological signal). Pollen profiles show source sediments are predominantly from the lower Mississippi River drainage basin and exhibit species similar to those present in modern open Louisiana coastal marshes and swamps (i.e., *Taxodium distichum*, Cyperaceae, Graminae, Chenopodiaceae, and Asteraceae), and coastal to upland hardwood forests of the Mississippi River alluvial valley (i.e., *Pinus*, *Quercus*, *Carya*, and *Liquidambar styraciflua*).

CHAPTER 1
INTRODUCTION AND GEOLOGIC BACKGROUND

Previous research on Holocene Mississippi River deltaic deposits has shown that the current delta plain and associated shelf geomorphic features like barrier island chains and submerged shoals, formed as a result of cyclic delta-building events. The Mississippi has changed course multiple times in the Holocene, each time building a new delta complex. Frazier (1967) identified six major Mississippi delta complexes that have been deposited during the past 7,500 years. These deltas are, from oldest to youngest, (1) Maringouin (7,500-5000 yr BP), (2) Teche (5,500-3,800 yr BP), (3) St. Bernard (4000-2000 yr BP), (4) Lafourche (2,500-800 yr BP), (5) Balize (1,000 yr BP-present), and (6) Atchafalaya (400 yr BP- present) (Fig. 1).

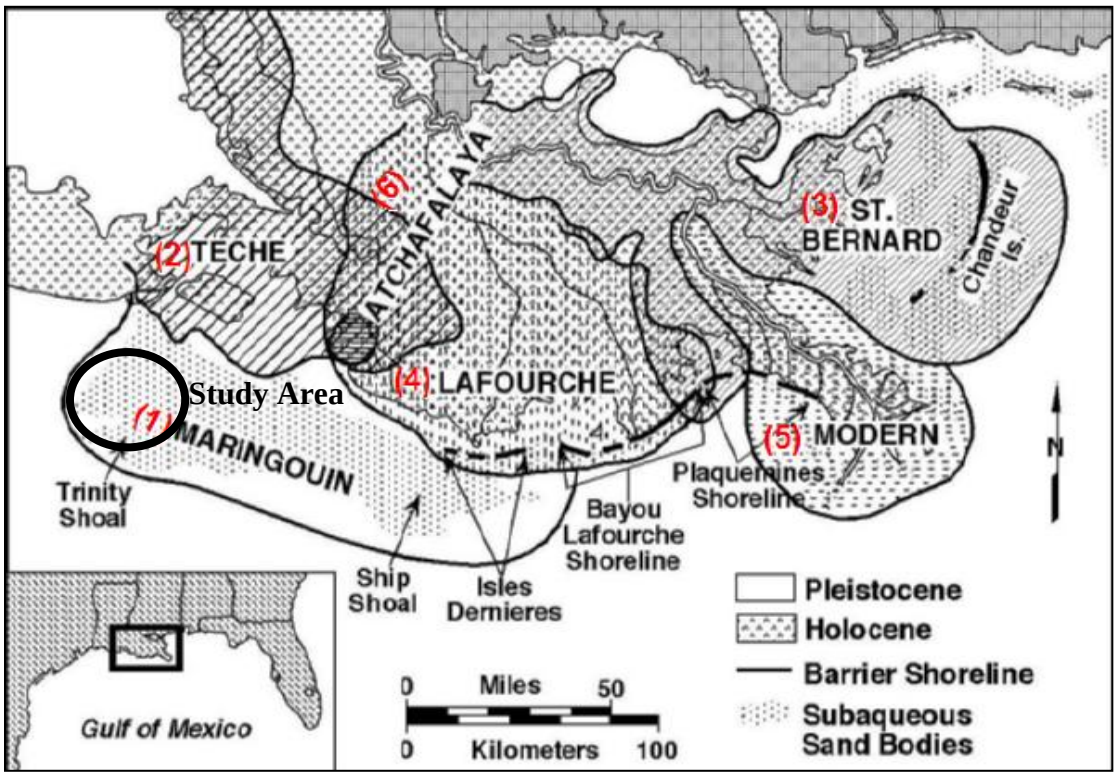

Figure 1. Map showing location of study area and major Mississippi River delta complexes (after Frazier, 1967)

Deltas complexes evolve through a constructive regressive phase of rapid growth and relative stability, followed by a destructive phase characterized by abandonment and transgressive reworking of delta sediments (Kolb and Van Lopik, 1958). Scruton (1960) coined the term delta cycle to refer to this cyclic pattern of deltaic sedimentation. McFarlan (1961) and Frazier (1967) later created a time framework for Holocene delta building established by radiocarbon dating. Delta building events have occurred on the frequency of about one cycle every 1-2kyr. As discussed by Roberts (1997), during these cycles, deltas undergo three phases of growth and abandonment; (1) rapid growth with increasing-to-stable discharge, (2) relative stability during initial stages of sediment loss, and (3) abandonment, followed by rapid subsidence-driven sub-aerial delta deterioration and transgressive reworking.

The research of Penland and Boyd (1981) and later Penland et al. (1988) established a three-stage comprehensive model for the marine-dominated transgressive phase of Mississippi River delta-plain depositional systems (Fig. 2). In stage 1, regressive sand deposits contained within abandoned delta headlands are reworked by longshore currents into spits and flanking barriers. Eventually the combined effects of subsidence and sea-level rise generate an intra-deltaic lagoon separating the stage 1 barriers from the coastline creating stage 2 transgressive barrier island arcs. These landward-migrating barrier island arcs cannot keep up with relative sea-level rise, subsidence, and loss of sediment supply associated with the retreating shoreline and are eventually submerged becoming stage 3 inner shelf shoals.

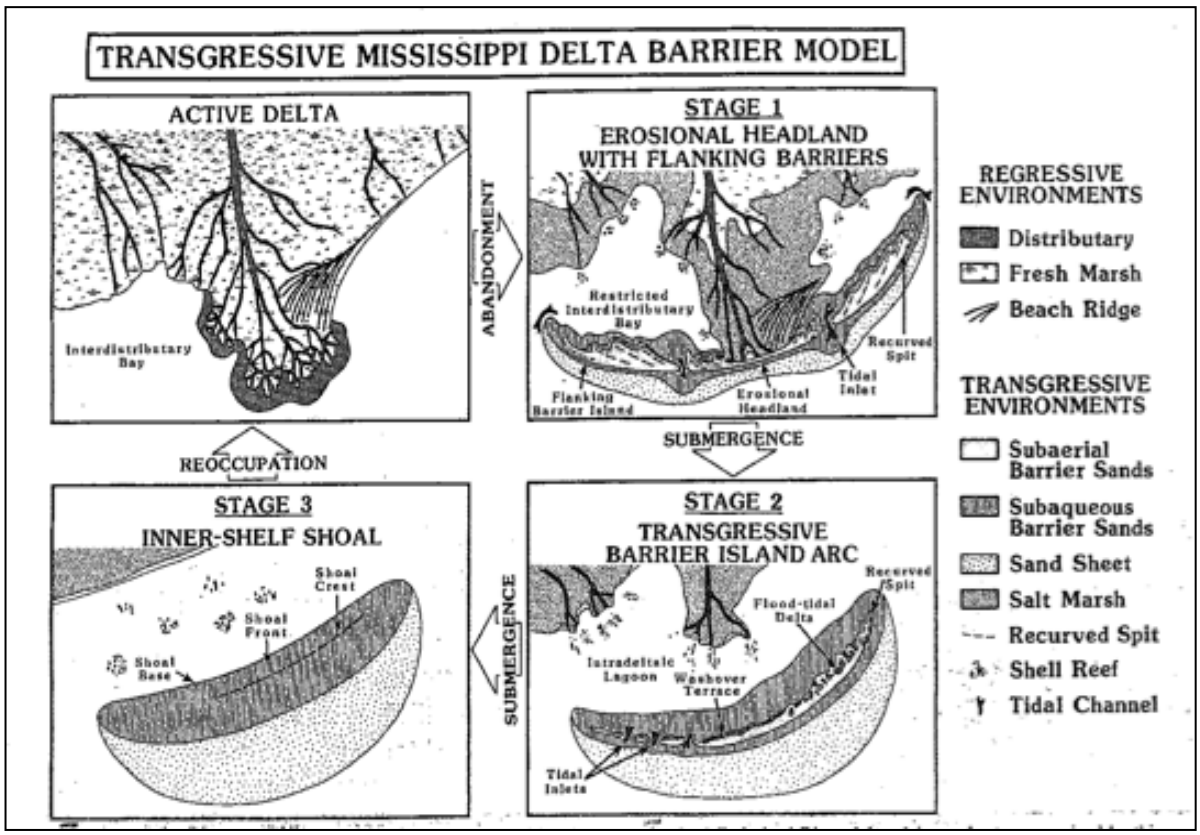

Figure 2. Diagram of three-stage comprehensive model for the marine-dominated transgressive phase of Mississippi River delta-plain depositional systems. (From Penland and Boyd, 1985)

During the Holocene transgression, five large sand shoals formed as the Mississippi River retreated across the delta plain (Penland et al., 1989), these are the Outer, St Bernard, Ship, Trinity, and Tiger shoals.

The Outer Shoal and the St Bernard Shoal are found along the -20 m isobath and were deposited in the early Holocene associated with a stillstand at ≈9000 yr B.P. (Penland et al., 1990). This project focuses on the Tiger and Trinity shoals, which are submerged inner-shelf shoals that along with Ship shoal formed as continuing rise in sea level submerged the Holocene shelf phase delta plain along the -10 m isobath (Penland et al., 1990). These shoals are shore-parallel sediment bodies located on the northern Gulf

of Mexico shelf, 40 km offshore of Chenière au Tigre (Chenier Plain) and Marsh Island, Louisiana (Fig. 3).

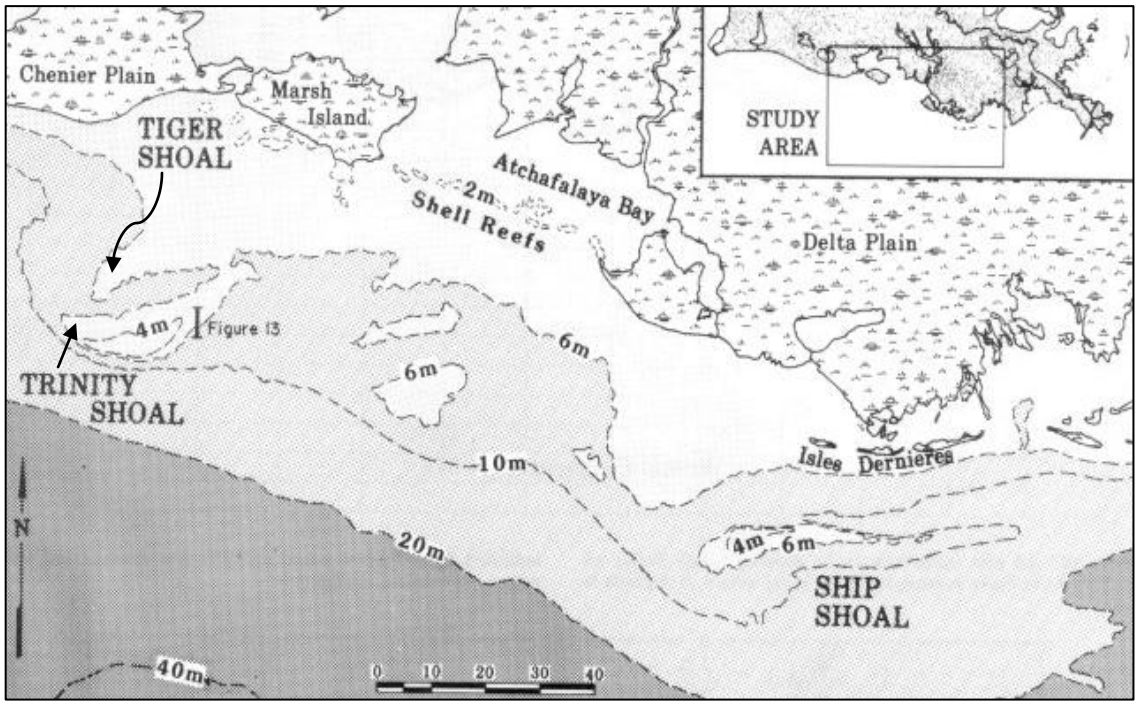

Figure 3. Location map of Tiger and Trinity shoals off Chenier Plain and Marsh Island, Louisiana (from the Louisiana Geological Survey, scale bar in km)

Tiger Shoal is about 12 km long and 1 km to 3 km wide, while to the south, Trinity Shoal is 30 km long and 5 km to 10 km wide. Lithology of the shoals is complex, with barrier sands near the top that overlay an assortment of interbedded sands, silts, and muds representing marsh, washover, lagoonal, tidal and pro-delta sediments deposited on the late Holocene delta plain. These trangressive sediment bodies are remnants of old delta lobes that have migrated to their present position under conditions of sea-level rise, shoreface erosion, submergence, and reworking which continue today. In the east, Trinity Shoal is in the process of being overlain by muds associated with deposition from

the Atchafalaya Basin (Penland et al., 1990). Continued progradation of the newly active Atchafalaya Delta is expected to eventually result in the burial of Trinity Shoal by fine grained sediments (Suter et al., 1985). These shoals make up the westernmost member of Mississippi River Delta avulsion complex that was interpreted as being associated with the Maringouin delta (7,500-5000 yr BP) by Frazier (1967). More recent studies (Penland et al., 1990) have linked the shoals to the Teche delta complex, giving a possible younger date of ~3,500 BP for the deposition of Trinity Shoal. But the overlap in timing of the Teche/Maringouin delta cycles, lack of accurate chronological data, and complex inter-layered geometry of avulsing delta lobes render high-resolution dating of these shoals difficult. Based on their marked difference in orientation, we also consider the possibility that each represents a different complex, one deposited during the Maringouin and one during the Teche phase.

This palynological project was designed as an attempt to decipher whether or not the Tiger and Trinity shoals were deposited within the same climatic cycle by reconstructing the paleoenvironments that characterized this region at the time of shoal deposition.

CHAPTER 2

OBJECTIVES AND HYPOTHESES

1) What were the environmental conditions on land and in the marine realm during the deposition Tiger and Trinity shoals?

The primary objective of this project is to characterize the paleoenvironment of southern Louisiana at the time of deposition of each shoal using palynomorph assemblages. Pollen and spores were used to characterize climate on land while dinoflagellate cysts and acritarchs were to be used to examine sea-surface conditions in the marine environment

2) Were the two shoals deposited during the same cycle or during periods with similar climatic conditions?

By comparing and correlating climatic signals across Tiger and Trinity shoals, it may be possible to evaluate whether or not these deltas were deposited under similar climatic conditions, hence evaluating the hypothesis (Fig. 4) that the sediments composing these shoals were deposited during the same delta cycle and thus better understanding the overall history of the Mississippi River drainage basin.

If indeed Tiger and Trinity Shoals were deposited during the same delta cycle, then we would expect no distinct differences in the pollen and dinoflagellate assemblages between the two shoals. If these shoals were deposited during two different cycles, then we should see either one or all of the following: a difference in dinoflagellate assemblages as a result of change in marine environment, a major difference in pollen and spore species as a result of climatic shift, and/or a difference in pollen and spore species as a result of a major shift in drainage basin.

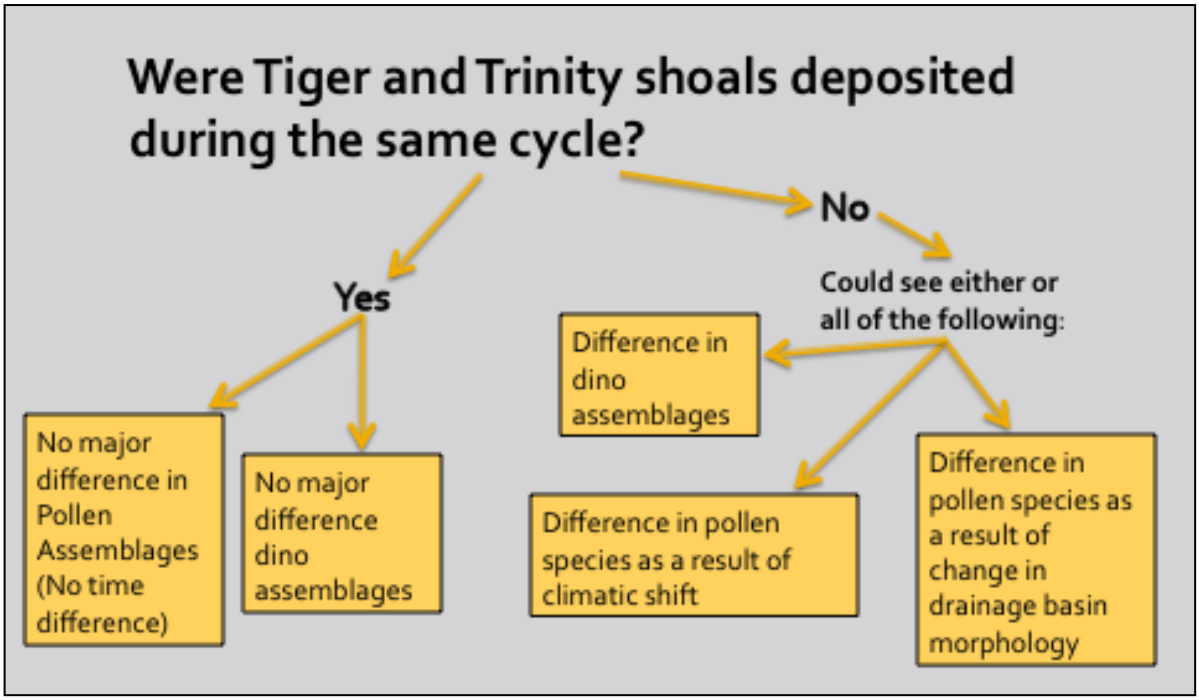

Figure 4. Diagram representing dual hypotheses and possible outcomes for this study

One limitation to keep in mind is the possibility that these shoals were deposited during separate cycles, but present similar palynological signals because the vegetation at the time of each depositional episode did not change drastically. In this case, resolution will not be sufficient enough to discern minor changes in drainage basin or climate that do not affect the pollen signal.

Assemblages may also reflect an extraordinarily warm dry period of the middle-Holocene known as the Hypsithermal Interval (8,500-4,000 B.P.) which mainly spans the Maringouin interval, but also includes some of the Teche interval of deposition. During the Hypsithermal Interval, prairies of the Central United States expanded west at the expense of forests (Delcourt, 1985). This said, hypsithermal drying was not as severe in the Gulf Coastal Plain, as coastal plain species characteristic of wetland environments expanded in the middle-Holocene, and reflected a warm and wet regional climate. At the end of the Hypsithermal Interval, a change in evergreen forests occurred in the Southeast

around 5,000 B.P. At that time, coastal plain forests that had previously been dominated by species of oak and hickory, became dominated by southern pines (Delcourt, 1980; 1985). Changes in vegetation of this nature may be evident in the pollen record at this location depending on the timing of the deposition of the shoals. Throughout the remainder of the Holocene, coastal swamps and wetlands have continued to expand under conditions of rising sea-level (Delcourt, 1985). The Teche Delta complex was deposited during a mostly warm period at a Holocene climate optimum, while the Maringouin Delta complex was deposited during a prior climatic optimum that lasted longer and transitioned to the Teche system by two long periods of relatively lower temperatures (Fig. 5). By looking at environmental indicators at each sampled site, it might be possible to piece together the paleoenvironment of these shoals and the time interval or complex to whivh they relate.

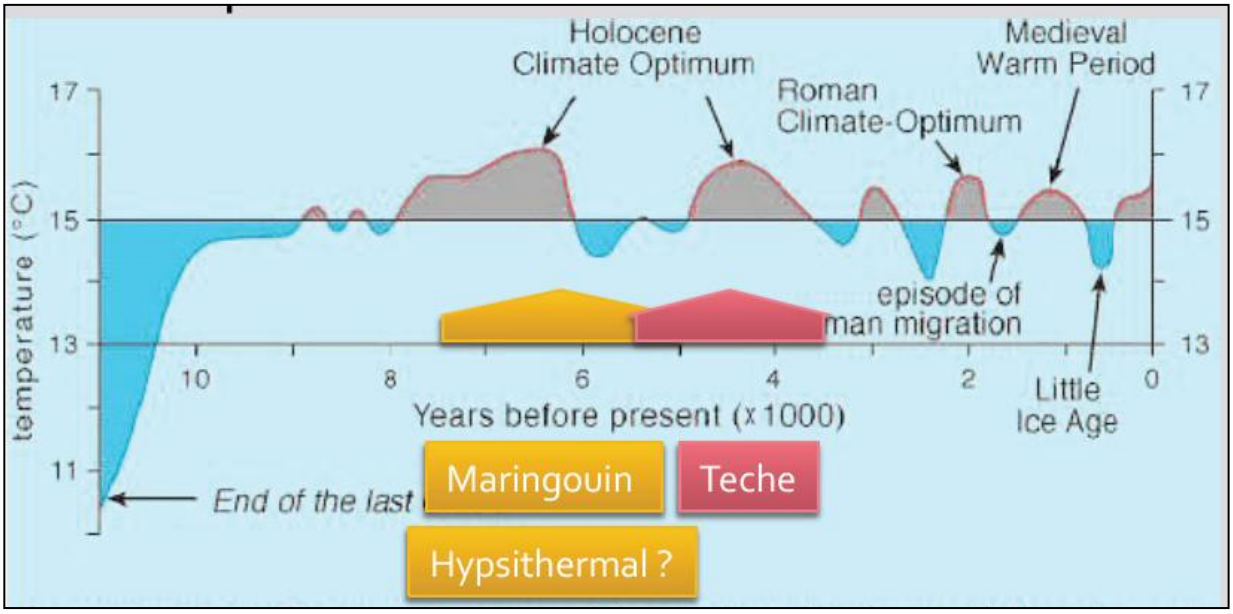

Figure 5. Average near-surface temperatures of the northern hemisphere during the past 11 kyr (modified after Dansgaard et al., 1969; and Schonwiese, 1995)

Palynological assemblages will also be evaluated in light of other Holocene temperature variation and sea-level curve studies. If either Tiger or Trinity Shoal were deposited during the warm period coincident with a mid-Holocene highstand (Blum, 2001), then we would expect the palynomorph assemblages to reflect a warm, wet regional climate. This study may not be of sufficient resolution to allow for any assumptions to be made about Holocene sea-level, but when tied to stratigraphy and chronology currently in preparation (by LSU PhD candidate Clint Edrington), environmental data along with concurrent unpublished studies incorporating chronostratigraphic resolution from carbon dating of foraminifer tests (by undergraduate student Chris Murley) may shed light on the current Holocene sea-level debate. Anderson et al. (1991) called for traditional views of episodic but gradual sea-level rise during the Holocene until reaching present levels. Blum (2001) suggested that sea level was slightly higher (+2m) in the mid-Holocene than the present using calibrated ^{14}C ages from foraminfer tests found in relict inland beach ridges that ranged from 6800-4800 yr BP.

3) What can be said about the provenance of the organic material present within the shoals?

. Chmura et al. (1999) showed that the primary source of marine pollen and spore assemblages in surface sediments from the Louisiana continental shelf in the vicinity of the Mississippi River plume is the main stem Mississippi, rather than nearby coastal areas like the Atchafalaya Basin. Thus, pollen deposited in these coastal waters probably primarily provides a record of vegetation in the lower Mississippi drainage basin and central to southern Louisiana. It is also possible, due to frequent river avulsion,

and history of capture of the Red River by the Mississippi River at times, that much of the sediments may be of Red River basin origin. We note however that Red River pollen signals may be thoroughly diluted by inputs from the main stem of the Mississippi River. In the case of strictly Red River sediments we would expect a more arid palynological response with some species characteristic of prairie environments, and oak forests of the lower Red River drainage basin. By analyzing species it may be possible to estimate the relative contribution of the Red River at this location.

The use of palynology as a stratigraphic and paleoenvironmental tool provides a different viewpoint in the ongoing attempt to understand Holocene Mississippi River deltaic systems. Understanding the delta cycle is important when classifying not only the geometries of sand bodies but also their stratigraphic relationships as well as the paleoenvironmental conditions at the time of sediment deposition. This type of knowledge is important to the geoscience and petroleum industries as the search continues for sediment bodies acting as hydrocarbon reservoirs. As coastal areas and sediments continue to compact and subside, engineers will undoubtedly need to understand the natural processes affecting deltas and coastlines. '*A clear understanding of the fundamental processes and products of the delta cycle provides a framework for predicting the behavior of a delta within the Mississippi River Holocene deposits*' (Roberts, 1997).

CHAPTER 3
METHODS AND MATERIALS

During September and October 2008, fifty-five vibracores were taken at select locations and depths within Tiger and Trinity Shoals (Fig. 6). Studies of pollen transport and deposition in coastal plain waters (Chmura and Eisma, 1995) indicate that individual pollen grains generally display the same pattern of deposition as fine-grained clastic sediments. Due to the effects of sorting and winnowing of fine clay to silt-sized palynomorphs from the sandy upper shoal sediments, samples were selected in fine grained, silty or clay-rich horizons within and directly below the shoals. The palynological content of these sediments are intended to represent a spatially averaged assemblage of the sediments of each shoal as a whole, as well as the surface water (dinoflagellate), and the drainage area (pollen and fresh-water algae) that produced them.

Sediment samples were chosen for palynological analysis and sent to Geolab in Alberta, Canada for processing. Following directions provided by Dr. Warny and I, the lab used a standard processing method, involving successive treatment of dry sample with hydrochloric acid, hydrofluoric acid, as well as heavy liquid flotation, ammonium hydroxide oxidation, sieving to retain the 1-100μm size fraction, and staining with saffranin red dye for color (Brown, 2008). Fifteen-gram sediment samples were spiked with two *Lycopodium* (club moss) spore marker tablets (batch number 124961 with 12,542 spores per tablet) to allow for calculation of the palynomorph concentration according to the following equation:

P_{conc} (grains/g) = (Lycopodium added/Lycopodium count) x (Pollen count/g)

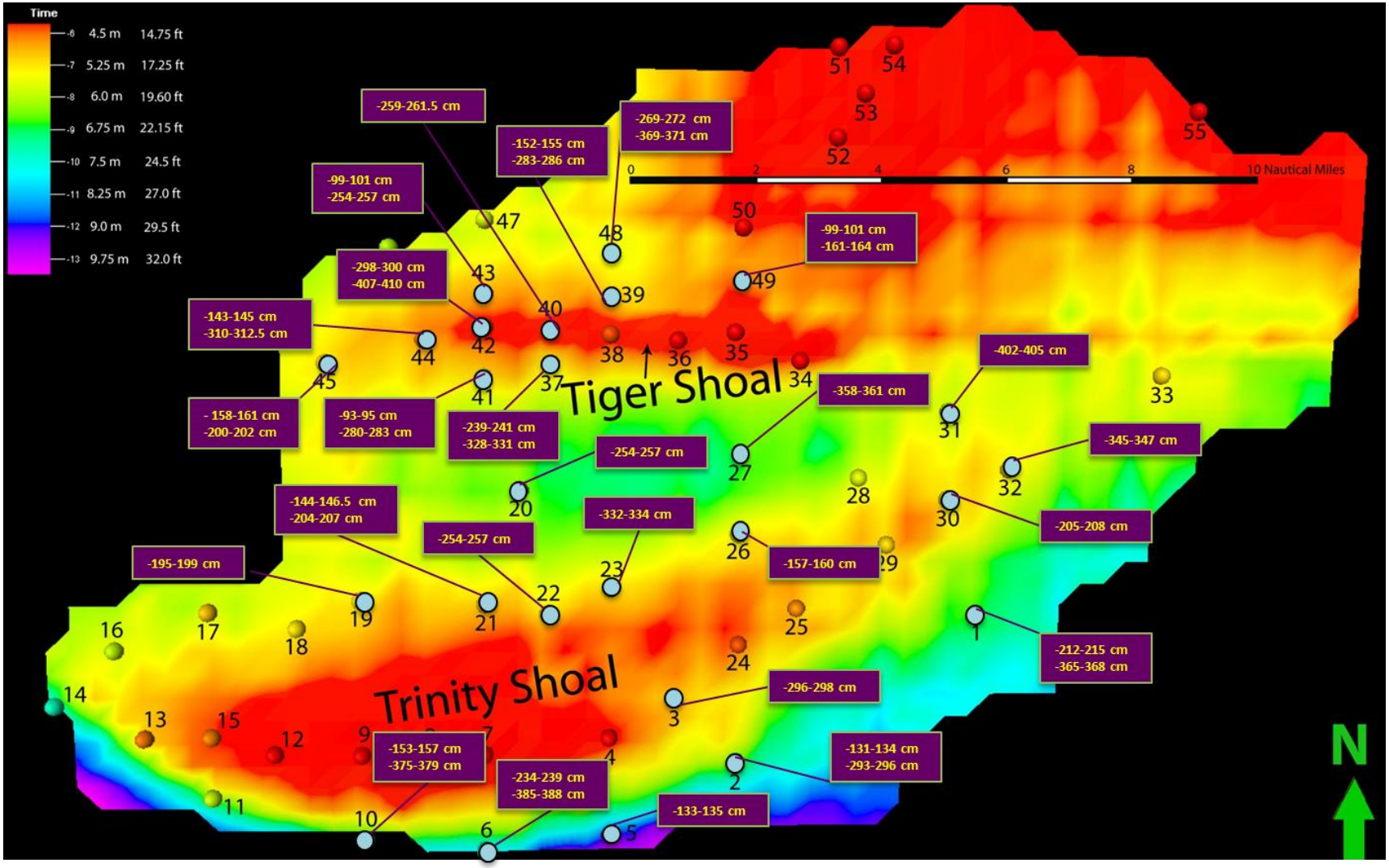

Figure 6. Converted time-depth bathymetric map of Tiger and Trinity shoals showing vibracore locations and palynological sample depth intervals

After processing, a drop of the palynological residue was mounted to each slide. Species were counted using a Olympus BX41 transmitted light microscope, with an oil immersion 60X magnification objective, and mounted micrometer for species sizing.

Forty palynomorph slides were analyzed for this study. They are listed and described in Table 1. Quantitative analysis was performed on all samples to provide paleoenvironmental determinations. Attempts were made to identify specimens down to the species level. However, many of the common groups recovered from this study include species that are not identifiable at the species level with the use of a transmitted light miscrope (i.e. Graminae, Chenopodiaceae). In this case, the genus or family was identified. Pollen reference material used for species identifications included a pollen catalog for the United States (Kapp, 1969), a five-part atlas of pollen of Louisiana (Lieux, 1980a, 1980b, 1982, 1983; Lieux and Godfrey, 1982), an atlas of Florida everglades pollen (Willard et al., 2004), and an atlas of pollen of the Southeastern United States (Jones et al., 1995).

In order to make sound statistical analysies of the results, counts of 300 pollen grains (terrestrial) and 300 dinoflagellate and other organic-walled algae (marine) per sample were attempted. After examining the palynological assemblage present, it was determined that marine species were sparse (<2%) and those present were damaged and thus most likely recycled at nearly all sites. Counts were changed to 400 pollen grains per sample, and marine grains present were counted until the terrestrial limit of 400 was reached. All pollen counts were derived from 400 total grains counted at each site.

Pollen counts were tabulated and relative abundances of major pollen groups were graphed in pie charts for each sample. Bar graphs of total counts for dominant pollen

Table 1. Sample description table with depth below surface and lithology

Sample Description Table		
Sample (core) #	Depth	Lithology
TT-01	212 cm	silt
TT-01	365 cm	sandy silt
TT-02	131 cm	sandy silt
TT-02	293 cm	sandy silt
TT-03	296 cm	sandy silt
TT-05	133 cm	fine sand
TT-06	234 cm	sandy silt
TT-06	385 cm	fine sand
TT-10	153 cm	sandy silt
TT-10	375 cm	sandy silt
TT-19	195 cm	sandy silt
TT-20	254 cm	sandy silt
TT-21	144 cm	sandy silt
TT-21	204 cm	fine sand
TT-22	254 cm	sandy silt
TT-23	332 cm	sandy silt
TT-26	157 cm	silt
TT-27	358 cm	silt
TT-30	205 cm	silt
TT-31	402 cm	sandy silt
TT-32	345 cm	sandy silt
TT-37	239 cm	silt
TT-37	328 cm	silt
TT-39	152 cm	silt
TT-39	283 cm	silt
TT-40	259 cm	sandy silt
TT-41	93 cm	silt
TT-41	280 cm	sandy silt
TT-42	298 cm	silt
TT-42	407 cm	silt
TT-43	99 cm	sandy silt
TT-43	254 cm	silt
TT-44	143 cm	sandy silt
TT-44	310 cm	sandy silt
TT-45	158 cm	sandy silt
TT-45	200 cm	sandy silt
TT-48	269 cm	sandy silt
TT-48	369 cm	sandy silt
TT-49	99 cm	sandy silt
TT-49	161 cm	sandy silt

groups (Arboreal, Non-Arboreal, and Aquatic) were also included at each site. Samples were then plotted along eight transects within the context of stratigraphy. This was done using stratigraphic interpretations for each core produced by LSU PhD student Clint Edrington for his ongoing dissertation that focuses on the sedimentological analysis of the shoals. These eight transects were created to better understand the relationship between the palynological signal and the shoal geometry (Fig. 7). Lines 1 through 4 are north to south dip profiles that cut through both of the shoals with line 1 being the easternmost profile and line 4 being the westernmost profile. Lines 5 and 6 are west to east strike profiles through the main bodies of Trinity (line 5) and Tiger (line 6) shoals. Lines 7 and 8 are strike profiles in between the shoals (line 7) and on the seaward side of the shoals (line 8).

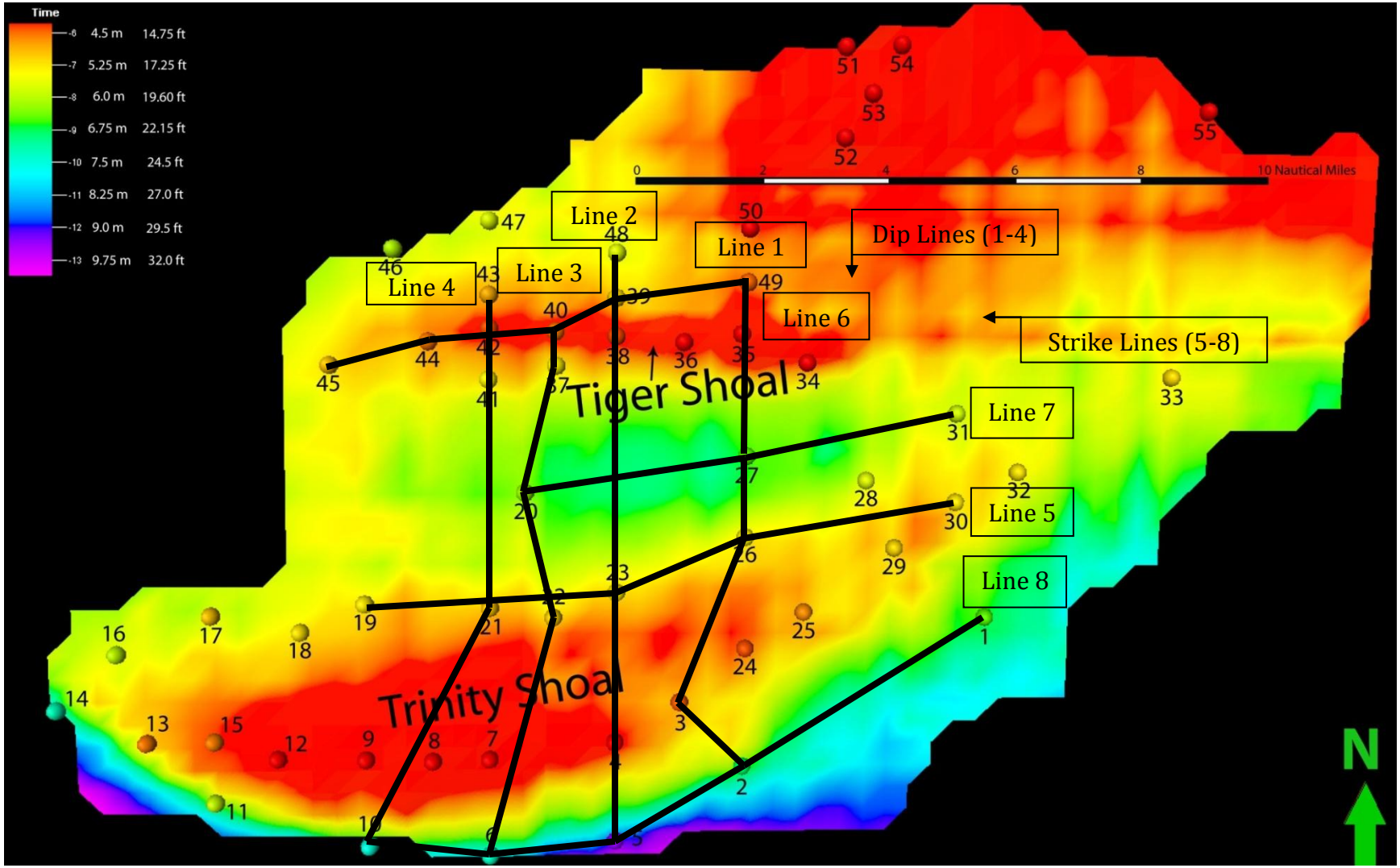

Figure 7. Converted time-depth bathymetric map of Tiger and Trinity Shoals showing location of palynological samples along the eight transects

CHAPTER 4

DATA

1) Species diversity recovered

All samples provided diverse terrestrial pollen assemblages (Appendix A Plates 1-9). Pollen species were grouped by plant and environmental associations; these include arboreal, non-arboreal, aquatic, and shrubs. Pollen species groups as well as specimens occurring most abundantly or of special ecologic significance are outlined in summary table 2.

Table 2. Summary table of pollen groups and species

Summary Table of Pollen Species		
Species Groups	**Key Species Present**	**Minor species present**
Arboreal (Plates 1-3)	*Pinus* spp. (Pine species) *Quercus* spp. (Oak species) *Carya* spp. (Hickory species) *Liquidambar sytraciflua* (Sweet Gum)	*Ulmus* sp (Elm) *Ostrya virginiana* (Hophornbeam) *Juglans nigra* (Black Walnut) *Tilia americana* (American Basswood)
Non-Arboreal (Plates 4-5)	Chenopodiaceae (herbaceaous plants) Graminae (true grasses) Asteraceae (Aster Family) Magnoliaceae (Magnolia Family)	*Ribes curvatum* (Granite Gooseberry) *Brunnichia ovata* (Buckwheat Vine)
Aquatics (Plates 6-7)	*Taxodium distichum* (Bald Cypress) Cyperaceae (Sedge Family) *Typha latifolia* (Bulrush) *Planera aquatica* (Water Elm)	*Nymphaea odorata* (American White Water Lily)
Shrubs, Freshwater, and Reworked (Plates 8-9)	*Myrica heterophylla* (Swamp Bayberry) *Myrica inodora* (Scentless Bayberry) *Pediastrum* (Freshwater algae)	*Ilex glabra* (Inkberry) *Alnus serrulata* (Hazel Alder) *Tasmanites* (Freshwater algae) *Aquillapollenites* (reworked Cretaceous angiosperm pollen)

General overview:

In addition to pollen and dinoflagellates species, freshwater algae were recovered from the samples. They included varieties of *Pediastrum* and *Tasmanites* algae (Plate 8). Negligible amounts of reworked pollen were also found in the samples, they were predominantly of *Aquillapollenites* (Cretaceous angiosperm pollen, see plate 8).

Relative abundance of each palynomorph group (Arboreal, Non-Arboreal, and Aquatic) as well as counts of major species dominating the palynological assemblages were plotted along four strike and four dip transects in order to examine pollen counts across the two shoals (see Appendix B: Lines 1 through 8). The dip lines cut through Tiger Shoal in the north and Trinity shoal in the south. Two strike lines are unique to each shoal, and the other two are in between the two shoals and to the south on the seaward side. Details of pollen distribution at these sites are presented below, organized by major pollen groups.

Arboreal Species (Plates 1 to 3)

Tree pollen proved to be the most abundant constituent at each site. Arboreal pollen signatures were comparable and made up about 40% to 50% at all locations in both Tiger and Trinity Shoals with the exception of sites 26, 30, 31, and 32 in the eastern end of Trinity Shoal where abundances dropped to ≈ 25%. Dominating the arboreal pollen types were species of *Pinus*, generally representing more than 75% of tree pollen (30% of total pollen) present. The remaining percent was represented by species of *Quercus*, *Carya*, and *Liquidambar styraciflua*. Other arboreal plants present in minor

amounts (less than 2%) included *Ulmus* sp., *Ostrya virginiana, Juglans nigra*, and *Tilia americana.* Decrease in arboreal pollen in the eastern end of Trinity shoal can mainly be attributed to drop in species of *Pinus.* All species but *Pinus* had comparable profiles at all sites, generally having ≤ 30 grains per sample or ≤ to 7.5% of the total pollen assemblage.

Aquatic Species (Plates 6 and 7)

Second to arboreal abundances were those of aquatic plant species. Aquatic species were similar at all locations, ranging from 25% to 35% of total abundance. Decline in arboreal pollen at aforementioned sites in the eastern end of Trinity shoal is accompanied by a rise in aquatic pollen to nearly 50%. Aquatic profiles were dominated by the species *Taxodium distichum*, also known as the bald cypress. The rise in aquatic abundance in the east of Trinity Shoal can be attributed to a 200% increase in the amount of *Taxodium* pollen compared to all other locations. Other important species, were sedges of the Cyperaceae family, along with *Typha latifolia*, and *Planera aquatica*. Though aquatic abundances go up in the east, abundances of these species at those sites remain comparable to all other locations and were typically ≤ 30 grains per sample or ≤ to 7.5 % of the total pollen assemblage. Specimens of *Nymphaea odorata*, the water lilies, were also present at the sites, but in low quantity.

Non-Arboreal Species (Plates 4 and 5)

Non-arboreal pollen accounted for ≈25% of the relative abundance at each site with no distinct changes in assemblage or abundance across the two shoals, including the

eastern end of Trinity Shoal. The most abundant species were of the families Chenopodiaceae and Graminae (≈30-50 grains/sample or ≈ 7.5 to 12.5% of the total pollen assemblage). In terms of overall abundance of individual grains, Chenopodiaceae and Graminae were second only to the two dominant species *Pinus* and *Taxodium distichum.* These were followed by various species of the families Asteraceae and Magnoliaceae. Minor species included *Ribes curvatum and Brunnichia ovata*.

Shrub Species (Plates 8 and 9)

Shrub species were a minor component of pollen profiles making up less than 5% of counts at all locations. Shrub pollen profiles were the same at all locations. Most commonly present was the species *Myrica heterophylla*. Seldomly present were the species *Myrica inodora, Ilex glabra,* and *Alnus serrulata*.

Typical abundances for Tiger Shoal and the western end of Trinity Shoal were ≈40-50% arboreal, ≈20-25% non-arboreal, and ≈25-35% aquatic. In the eastern end of Trinity Shoal abundances abruptly change to ≈25% arboreal, ≈20-30% non-arboreal, and ≈ 40%-50% aquatic. Marine and freshwater species combined generally accounted for <10% of species present, indicating that the sediments sampled are predominantly of terrestrial origin.

2) Species concentration measured

Pollen concentrations were mapped across the shoals using a circle plot diagram to display concentration distribution. All concentrations were in the range of 5,000-30,000 grains per sample.

Pollen concentrations of Tiger Shoal were higher than those of Trinity Shoal (Fig. 8). Sediments of Tiger Shoal showed pollen concentrations generally in the range of 10,0000 to 20,000 grains per gram of sediment, while concentrations in Trinity Shoal were roughly 5,000 to 10,000 grains per gram. Both shoals had concentrations comparable to concentrations of pollen found in shelf sediments of the Mississippi River plume on the Louisiana shelf (4,000 to 40,000 grains/g; Costello, 1992).

3) Geographical distribution of species

Pollen profiles were examined along transects (Appendix B: Lines 1-8) in order to determine geographical distribution. Four dip lines and four strike lines were constructed. As mentioned above, the dip lines (1-4) are oriented from north to south cutting through Tiger then Trinity Shoal, starting from the east (Line 1) and going to the west (Line 4). The strike lines (5-8) are oriented from west to east. Lines 5 and 6 go through Tiger and Trinity Shoal respectively. Line 7 is located between the shoals, and line 8 is on the seaward side of the shoals.

Dip Lines (see Appendix B: Lines 1-4)

Line 1goes through sampling sites 49 and 27 in the east of Tiger Shoal, and sites 26, 3, and 2 in the east of Trinity Shoal. Profiles of arboreal, aquatic, and non-arboreal species were relatively similar across this transect, other than site 26 in the eastern portion of

Trinity Shoal. At this site, arboreal pollen dropped from 45% to ≈ 25% of the sample. Lower arboreal abundances at these locationa are attributed mainly to a drop in pine pollen. Aquatic pollen species at this site rise from 25% to ≈ 35-40% due to a two- fold increase in bald cypress pollen. A general eastward increase in bald cypress in Trinity Shoal is also noted.

Line 2 includes sites 48 and 39 in the middle of Tiger Shoal, as well as sites 23 and 5 in the middle of Trinity Shoal. Pollen profiles across this transect are nearly identical through both shoals. Counts were about 25% aquatic, 30-35% non-arboreal, and 40-45% arboreal. Pine was the predominant species usually accounting for over 25% of pollen counts, while cypress accounted for ≈ 15%.

Line 3 goes through sites 40, 37, and 20 in the west of Tiger Shoal, and sites 22 and 6 in the center of Trinity Shoal. Pollen profiles across this transect are very similar through both shoals and are the same as abundances noted at sites along line 2 (25% aquatic, 30-35% non-arboreal, and 40-45% arboreal).

Line 4 connects sites 43, 42, and 41 in the east of Tiger Shoal with sites 21 and 10 in Trinity Shoal. On average, pollen abundances along this transect are similar to those of other dip lines, with the exception that arboreal abundances sometimes reach over 50%. Fluctuations in arboreal percentages are attributed to increases of pine pollen to over 37% of total abundance at sites 43, 41, and 10 in samples taken from the top 1.5 meters of sediment cores. Pine species are likely overrepresented in counts due to preferential ease of transport of these buoyant, bissacate pollen types, so some fluctuation in pine is to be expected, even within sediments of the same origin.

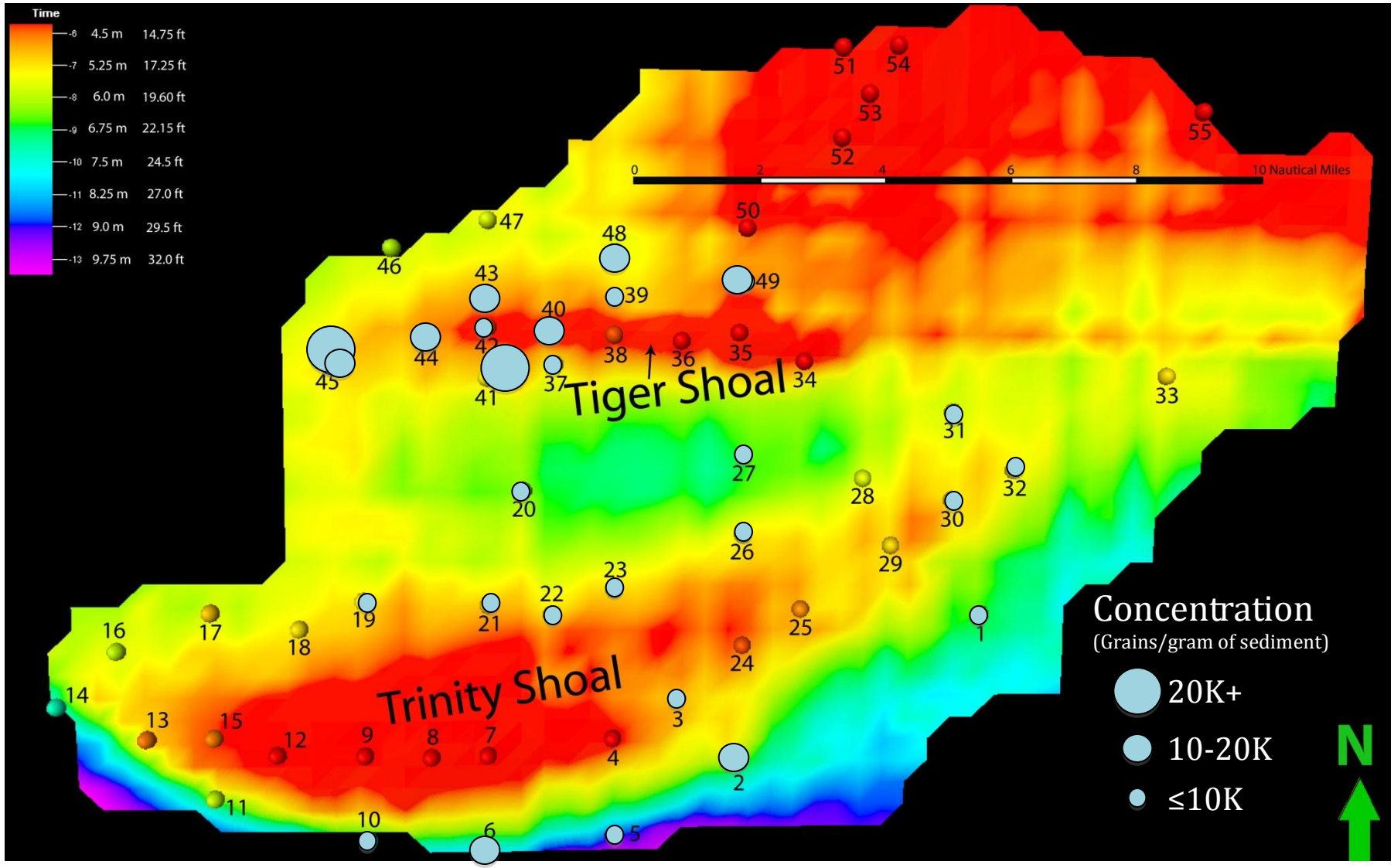

Figure 8. Converted time-depth bathymetric map of Tiger and Trinity Shoals showing pollen concentration.

Strike Lines (see Appendix B: Lines 5-8)

Line 5 is a west-east strike line through Trinity Shoal, sites 19, 23, 26, 30, and 32. This line shows the greatest degree of variability of pollen abundances of any of the 8 lines. Sites 19 and 23 show similar abundances to those seen in lines 2 and 3 (25% aquatic, 30-35% non-arboreal, and 40-45%). There is an abrupt change in pollen signal at site 26 in the east side of Trinity Shoal. Arboreal pollen counts drop significantly from 40-45% to 20-25% (mostly pine), and aquatic species increase from 25-35% to 40-45% (mostly bald cypress). A steady drop in pine and increase in cypress is noted from site 26 to 32. A significant increase in freshwater species is also noted at site 30.

Line 6 is a west-east strike line through Tiger Shoal, sites 45, 44, 40, 39 and 49. Pollen abundances along this transect are almost identical at all sites and are similar to those of lines 2, 3, and sites 19 and 23 (western portion of Trinity Shoal) of line 5 (25% aquatic, 30-35% non-arboreal, and 40-45% arboreal).

Line 7 is a strike line in the transitional area between the two shoals that goes through sites 20, 27, and 31. Sites 20 and 27 show similar abundances to those found in Tiger Shoal and the western portion of Trinity Shoal. Site 31 in the east shows an abrupt increase in cypress and decrease in pine similar to sites in the eastern portion of line 5 through Trinity Shoal.

Line 8 is a strike line on the seaward side of Trinity Shoal. Abundances along this transect were similar to those experienced throughout Tiger Shoal and the western portion of Trinity Shoal. Though this transect is entirely through sediments of Trinity Shoal, no abrupt change in abundances (as was seen in the eastern part of line 5) is noted.

In summary, species diversity and abundance of pollen were very similar at all sites within both shoals aside from four sites located in the eastern portion of Trinity Shoal. Abundances of key palynological groups in Tiger Shoal (Fig. 9) show only minor fluctuations across the shoal. The greatest degree of change noticed was in abundances of arboreal pollen (mainly pine). Abundances of key palynological groups in Trinity Shoal (Fig. 10) were very similar to those recovered in Tiger Shoal with the exception of sites 26, 30, 31, and 32, which show a major drop in arboreal species with an increase in aquatics.

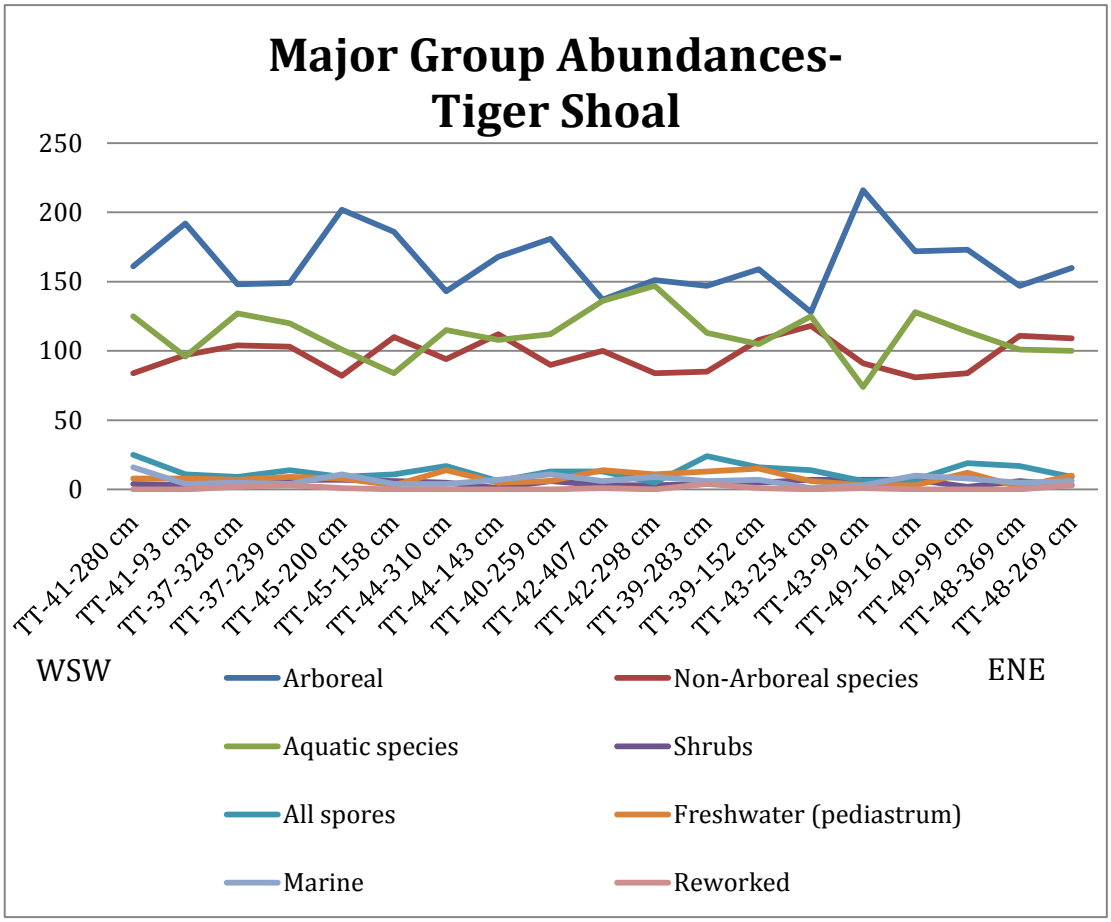

Figure 9. Major Pollen Group abundances for Tiger Shoal

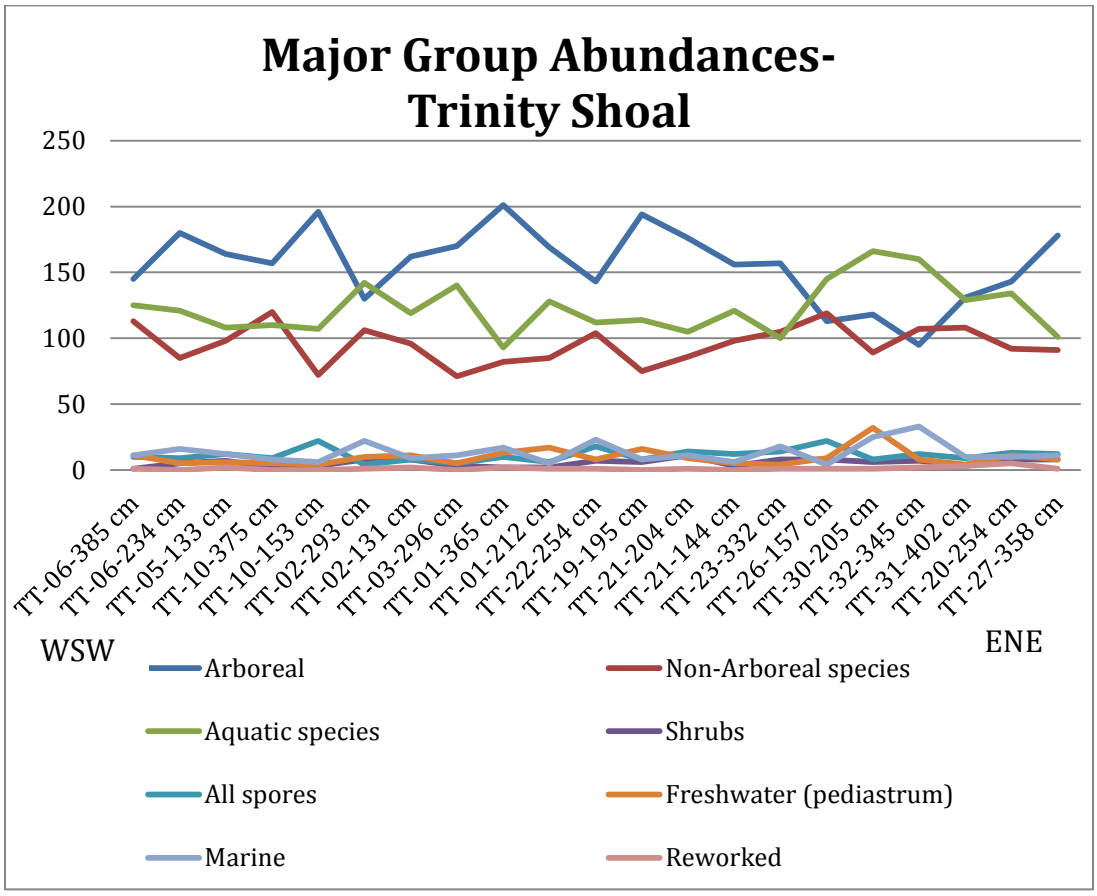

Figure 10. Major Pollen Group abundances for Trinity Shoal

CHAPTER 5
DISCUSSION

Palynological results gathered from this study provide three types of information regarding the genesis of the shoals. First, they provide data on the type of environments that surrounded the delta at time of deposition. Secondly, they allow evaluation of whether or not the two shoals were deposited at the same time or during two different cycles. And finally, the data provides information about the provenance of terrigenous organic-matter.

1) What is the environmental significance of palynological and foram assemblages recovered from the Tiger and Trinity shoals?

1a) Dinoflagellate cysts:

Marine microplankton in sediments of Tiger and Trinty shoals were sparse (< 2% relative abundance) and many organic-walled phytoplankton were most likely reworked judging from the poor preservation of the specimens recovered. Low dinoflagellate abundances indicate that 1) most likely sediment input at the time of deposition was overwhelmingly terrestrial and/or 2) that the environment was not suitable to sustain a healthy dinoflagellate population. The first hypothesis is to be expected of sediment-laden water that is brought to the Gulf of Mexico by the Mississippi, the largest river system in North America (Kammerer, 1990).

It is likely that the Mississippi River was introducing a great deal of fresh water during deposition – just as it does today - diluting Gulf of Mexico waters and creating sea-surface salinities too low for dinoflagellates to survive or thrive. To test this hypothesis, sediment samples were taken at coastal areas near the modern Mississippi River delta (Fig. 11 and Table 3). All samples processed thus far from sites where sea-

surface salinities are 10 per mil or less are essentially barren in dinoflagellate cysts. Based on this modern analogue set of data, we propose that the lack of dinoflagellate cysts in both shoals must primarily reflect a very low sea-surface salinity at the time of deposition, and that the few dinoflagellate cysts present were diluted by the major input in terrestrial palynomorphs.

Figure 11. Map of some of the many salinity sample locations near modern Mississippi River Delta (courtesy of Erick Swenson).

Table 3. Sample salinity table for Mississippi River Delta map locations

Sample #	Salinity
1	2.69
2	2.72
3	3.31
4	2.87
5	2.21

1b) Foraminifera:

An undergraduate research project was conducted to assist this master thesis project . For this project, sediment from the core intervals sampled in this palynological study were washed and sieved on a 53 micron-mesh, and benthic foraminifera were picked by Chris Murley from the residue. Species of two genuses are dominating the foramifer assemblage; they are *Ammonia* spp. and *Elphidium* spp. (Fig. 12). These genuses are commonly found in Gulf coastal waters in environments including lagoonal and back-barrier/fringe marsh (protected and exposed) (Sen Gupta et al., 1996; Woo et al., 1997). This low diversity, low-salinity tolerant foraminifer assemblage tends to confirm that the salinities were indeed too low to allow dinoflagellate to thrive at the time of deposition of both shoals.

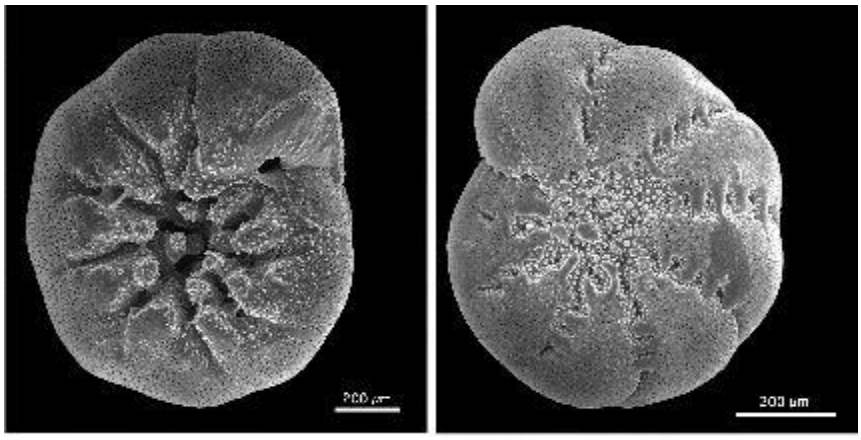

Figure 12. Common Gulf Coastal species *Ammonia beccarii* (left), and *Elphidium excavatum clavatum* (right). From Thomas et al., 2000.

1c) pollen:

With the exception of four sites (26, 30, 31, 32) in the eastern end of Trinity Shoal, palynological profiles were remarkably similar across the shoals. The pollen profile of Tiger Shoal and all but the eastern end of Trinity Shoal showed comparable

species and abundances. Key species recovered from the samples are described below and their environmental significance is discussed. Species are described in order of abundance, starting with the dominant species.

Pinus (Pine) – Appendix A: 1.1, 1.2, 1.3 and 2.1

Today, species of pine dominate in upland hardwoods and longleaf pine forests that cover nearly half the state and surround the Mississippi alluvial valley (Fearn, 1995), so it is not surprising to find them in the studied samples. Pine species dominated at all sites but the outlier locations in the east of Trinity Shoal. These wind-pollinated types are produced in great quantity and likely over-represented in the flora, as compared with some other angiosperms that produce relatively fewer pollen that are pollinated by insects or other means, or are not as easily transported. Another factor in consideration is the fact that pine pollen are bisaccate. Because, of this unique morphological feature, pine pollen are commonly abundant in deltaic environment as the two laterally-placed vesicles make them uniquely well adapted for widespread dispersal farther offshore than other terrigenous organic matter or pollen grains (Habibet al., 2005).

But aside from the morphologically-driven dominance in deltaic realm, it is also note that by 5,000 B.P., coastal plain forests that had previously been dominated by species of oak and hickory, became dominated by southern pines (Delcourt, 1980, 1985). Though pine species are typically over-represented in pollen counts, dominance of pine pollen in these shoals may indicate that deposition of these shoals postdates the shift in coastal plain forests that took place at 5,000 B.P.

If we were to attribute an environmental significance to the pine signal – other than the morphological consideration - the decline in pine pollen in the eastern end of Trinity Shoal may be attributable to Atchafalaya muds overlying pinching out shoal sediments at the surface where samples were taken as suggested by Penland et al. (1990). Sediments of the Atchafalaya basin should be high in locally abundant species found in swamp and marsh areas (i.e., *Taxodium distichum*) with minor wind input of pine because the Atchafalya Basin is the largest swamp in North America and completely dominated by species of cypress.

Taxodium distichum (Bald Cypress) – Appendix A: 6.1, 6.2, and 7.1

At present, this species of cypress grows mainly in swamps along the Gulf Coast, and along small streams and rivers in areas with wet soils (Elsik, 1969). Cypress swamps would have been commonly found growing in the Mississippi alluvial valley throughout the Holocene as well as in coastal swamp and marsh areas. Increases of *Taxodium* pollen in the east end of Trinity Shoal likely represent Atchafalaya basin sediments. The Atchafalaya basin is the largest swamp in North America and the dominant plant group is cypress. When comparing the results of this study with those of the modern Mississippi and Atchafalaya rivers published by Chmura (1999), it is found that *Taxodium* abundances in Tiger Shoal and from the western portion of Trinity Shoal are similar to those found in modern pollen profiles of Mississippi River water (≈15%), while abundances in the east of Trinity Shoal are similar to those of Atchafalaya River water (≈40%).

Based on the abundance of this species, the climate at the time of deposition of both shoals was likely warm and wet throughout. This combined with continued creation of swamps and marshland by rising sea-level creating inundated areas that supported the spread of large cypress-swamp forests along the Holocene shoreline.

Chenopodiaceae (Goosefoot) – Appendix A: 4.1, 4.2, and 5.1

Species of the family Chenopodiaceae are herbaceous plants most abundant in shoreline areas like salt or brackish water marshes (Elsik, 1969). These types of areas would have been found along the coastline and surrounding low-lying areas like estuaries and barrier islands that would have formed as a result of sea-level rise and cyclic delta sedimentation. Chenopodiaceae profiles were comparable at all locations and stayed around 10% of total species abundance. These abundances are comparable to abundances of Chenopodiaceae tabulated from surface sediments taken from the Louisiana delta plain (Chmura, 1999). Currently, marshes in Louisiana extend around 30-50 miles inland from the Gulf of Mexico across the entire southern end of the state, and the presence of species of Chenopodiaceae is indicative of marsh sedimentation.

Graminae (true grasses) – Appendix A: 4.3, 4.4, and 5.2

Grasses of the Graminae family (true grasses) are most abundant in open areas such as marshes (Elsik, 1969). Abundances of Graminae were similar at all locations and were comparable to those of Chenopodiaceae (≈ 10%). Graminae and Chenopodiaceae would have existed together in Holocene coastal wetlands and marshes as they do today. These two families along with sedges of the Cyperaceae family are the dominant types of

vegetation currently found in marshes along the Gulf Coast. Profiles of Graminae in the shoals echoed those of Graminae found in surface sediments of the Louisiana coastal plain (Chmura, 1999). The presence of Graminae species implies marsh depositional origin of sediments.

Cyperaceae (Sedge Family) – Appendix A: 6.5, 6.6, and 7.3

Sedges of the Cyperaceae family are found in many locations but mainly as wetland plants associated with poor soils (Elsik, 1969). These plants would have flourished in Holocene coastal wetlands and marshes, around rivers and streams, and lakes and ponds (Tedford, 2009). Sedge abundances were less than those of Chenopodiaceae and Graminae and stayed at ≈7%. This is comparable to modern abundances of Cyperaceae on the Louisiana coastal plain (Chmura, 1999).

Typha latifolia (Bulrush) – Appendix A: 6.7, 6.8, 6.9, and 7.4

Bulrush, also commonly called cattail, is a perennial herbaceous plant which grows in marshes and wet areas of temperate and subtropical areas (USDA Plants Database). These types of plants would have existed in wetlands and coastal marshes along the Holocene shoreline. This species was present at all but 2 sites and abundances ranged from ≈ 3-8% indicating that it was a significant contributor to overall assemblages during deposition. This is yet another species that would indicate deposition of the shoals took place in a marsh or semi-marsh environment.

Quercus (Oak) – Appendix A: 1.4, 1.5, 1.6, 1.7, and 2.2

Species of oak are typically found in cool to warm temperate regions commonly found growing in association with species of *Carya* (Hickory and Pecan), (Elsik, 1969). These types of species would be found growing in bottomland hardwoods associated with the Mississippi alluvial valley and in upland forests surrounding the valley, as they do today (Fearn, 1995). Abundances of oak averaged ≈ 5% at all locations. This is slightly lower than the abundances of oak pollen in surface sediments on the modern Louisiana coastal plain (10-15%) (Chmura, 1999). Prior to 5,000 B.P. coastal plain forests were dominated by species of oak and hickory (Delcourt, 1980, 1985). Oak pollen signals do not seem to indicate that the regional vegetation at the time Tiger and Trinity shoals were deposited was oak-dominated forests. This information along with high abundances of pine pollen provides evidence that would tend to imply that these shoals were deposited after 5,000 B.P. after coastal plain forests had transitioned to pine dominance.

Asteraceae (Aster) – Appendix A: 4.5, 4.6, and 5.3

Members of the aster family are herbaceous plants found in temperate and subtropical regions and commonly found in brackish or salt-water marshes (Elsik, 1969). These species would have been found all along the Louisiana coastal interface in the Holocene. Abundances of Asteraceae stayed within the range of 2-5% at all sites. This is comparable to modern percentages in coastal waters (Chmura, 1999). Asteraceae species along with Cyperaceae, Graminae, and Chenopodiaceae, are assumed to be components of ground vegetation in coastal wetland marshes.

Carya glabra and *Carya illinoensis* (Hickory and Pecan) – Appendix A: 1.8, 1.9, and 2.3

Hickory and pecan are cool to warm temperate trees that are commonly found growing in association with other temperate trees like oak (Elsik, 1969). This type of species would be found growing in bottomland hardwoods associated with the Mississippi alluvial valley along with species of oak and sweetgum – two species that are also common in our assemblages. *Carya* species would also be found in the upland pine dominated forests. Some species of *Carya* are even found in swampy or inundated areas and around lakes or ponds (i.e. *Carya aquatica*) (Tedford, 2009). Abundances of *Carya* were around 2-3 % at all locations. Again, this would imply that the time frame of sedimentation of the shoals postdates 5,000 B.P., when species of oak and hickory no longer dominated coastal plain forests.

Liquidambar styraciflua (Sweetgum) – Appendix A: 1.10, 1.11, and 2.4

Sweetgum trees of the species *Liquidambar styraciflua* are found widespread across the state of Louisiana from dry sandy soils to flooded bottomlands (Tedford, 2009). Most commonly these species are found as bottomland hardwood species of the Mississippi River valley or as dominant species of upland forests (Fearn, 1995). Distribution during the Holocene should have been similar to that seen today. Abundances of *Liquidambar* were ≈1-2% at all locations. Low input of sweetgum at this location is attributed mainly to bottomland species found in the Mississippi River valley, rather than the upland forests which would probably carry larger abundances.

Planera aquatica (Water elm) – Appendix A: 6.3, 6.4, and 7.2

This species is found in the wet soil of swamps and inundated areas of the Mississippi alluvial valley (Fearn 1995; Tedford, 2009). It is most abundant along streams and lakes of floodplains (Lieux, 1980b). *Planera aquatica* was present at all but 3 sites and typical abundances were ≈ 1-2%. Presence of this species would indicate provenance from wet low-lying areas like coastal swamps, ponds and lakes, and around the Missippi River valley.

Shrub Species (*Myrica heterophylla* and *Myrica inodora*) – Appendix A: 8.1, 8.2, 8.3, 8.4, 9.1, and 9.2

Myrica heterophylla, commonly named swamp bayberry, and *Myrica inodora*, also called scentless bayberry, are both commonly found today in wetland areas of the southeast United States (USDA Plants Database). Small amounts of these species were found at most locations and abundances of both of these species combined for .5-2% of total pollen counts. These shrubs probably grew in coastal wetlands and boggy branch bottoms of pinelands of inundated areas near the Mississippi River (Lieux, 1980b).

Minor Species

Some other species were not present at all locations, and when present were typically not abundant (< 5 grains or less than 1.5%). These included:

Ulmus (Elm) - This species is common in the bottomland forests of the Mississippi alluvial valley (Fearn, 1995) in association with oak, hickory, and sweetgum.

Brunnichia ovata (Buckwheat Vine) - This is a species of climbing vine that grows primarily in bottomland forests and bordering rivers, swamps, and wet thickets. This vine is also common in marsh environments (Tedford, 2009).

Ribes curvatum (Granite Gooseberry) - This species is widespread and common in hard wood forests of northeastern Louisiana (Lieux, 1982).

Alnus serrulata (Hazel Alder) – This shrub species grows along streams and in wet areas like swamps and bogs in central and northeastern parts of the state (Lieux, 1980b).

Ilex glabra (Inkberry) - This small shrub species is very abundant in the southeastern part of the state (Lieux, 1983).

Ostrya virginiana (Hophornbeam) - This species is common as an understory tree in mountainous rocky areas of the eastern United States and in most upland areas including northwestern and eastern Louisiana. However, this species is absent from the wettest areas of lower flood plains (USDA Plants Database). The rare presence of this species in the assemblage probably denotes long-distance transport by the Mississippi River.

Nymphaea odorata (American white water lily) - This well-known species of water lily is commonly found in sawgrass marshes and wet prairie environments (Willard, 2004).

Tilia americana (American Basswood) - Basswood is widely distributed in the central and eastern United States, but generally absent from the Mississippi River flood plain (Lieux and Godfrey, 1982). Presence of this species, like that of *Ostrya virginiana* is noted as related to long distance transport.

Juglans nigra (Black Walnut) - Black walnut is widely distributed throughout the central and eastern United States, but is not abundant in Louisiana (Lieux 1980b).

2) Were the two shoals deposited at the same time and what are the implications for the timing of deposition?

Based on prior published studies, it is believed that the shoals were either deposited during the Maringouin (7,500-5000 B.P.) (Frazier, 1967), or Teche delta cycles (5,500-3,800 B.P.), (Penland et al., 1990). This time interval spans an interval of the middle-Holocene known as the Hypsithermal Interval (8,500-4,000 B.P.). During the Hypsithermal Interval, prairies of the Central United States expanded west at the expense of forests (Delcourt, 1985). Coastal plain species characteristic of wetland environments also expanded during this period, and reflected a warm and wet regional climate. By 5,000 B.P., a change had occurred in evergreen forests of the Southeast; coastal plain forests that had previously been dominated by species of oak and hickory, became dominated by southern pines (Delcourt, 1980, 1985). It is evident that both the Maringouin and Teche delta cycles should display wetland species characteristic of warm regional climates. However, the Maringouin period of deposition should display more species of *Quercus* (oak) and *Carya* (hickory) with respect to the Teche period. The overall assemblage found in the shoals would favor a deposition of the shoals associated with the Teche delta cycles.

Pollen signals were very similar in both shoals except for four sites (26, 30, 31, 32) in the eastern end of Trinity Shoal. These sites are coincident with an area described by Penland et al. (1990), where a few meters of Atchafalaya basin muds overly Trinity Shoal sediments. Increases in the relative abundance of the species *Taxodium distichum* (bald cypress) at these locations indicate an increase in swamp species which would be expected from Atchafalaya sedimentation, as the Atchafalaya basin is the largest swamp

in North America of which the dominant plant group is cypress. Results from the present study are in agreement with the Atchafalaya origin for this part of the shoals.

Other than this specific area, the similarity of pollen signals obtained from both shoals strongly favors the hypothesis that the Trinity Shoal and Tiger Shoal were deposited concurrently during the same depositional cycle. An alternate scenario is that these two shoals were deposited during somewhat different periods or cycles presuming that the vegetation at the time of each depositional episode did not change drastically.

The dominance of pine pollen (though pine species are generally over-represented in deltaic environments) may indicate that these shoals were deposited during a time when coastal and upland forests were dominated by species of pine. Species of oak (5%) and hickory (2%) were present but generally much lower than pine relative abundances, which were commonly over 30%. Pine dominated pollen assemblages tend to indicate that the deposition of Tiger and Trinity shoals postdates the change in dominance of coastal evergreen forest in the southeast that took place around 5,000 B.P. (Delcourt, 1980, 1985).

Based on these evidences, the hypothesis that sediments from both shoals were likely of Teche origin rather than Maringouin is favored.

One additional factor in favor of this hypothesis is the fact that pollen concentrations are noticeably higher in Tiger Shoal, particularly in the western end of Tiger Shoal, on the landward side. One possible explanation for this geometry is that the Tiger Shoal area was closer to sources of organic input (i.e. the shoreline and fluvial sources) at the time of deposition, compared to the Trinity Shoal. This concentration geometry is supported by Van der Kaars (2001) who concluded that pollen concentrations

in coastal areas typically decrease with distance from the shoreline. Concentrations may also reflect the degree of reworking these sediments have experienced. Trinity Shoal would have protected Tiger shoal from coastal energy and suffered more of the side effects of reworking and winnowing of the fine-grained fraction (including pollen) from shoal sediments.

3) What can be said about the provenance of the organic material present within the shoals?

Ninety nine percent of the species found in both shoals are species found today within 100 miles of the mouth of the Mississippi River. Species that could come from the Red River basin, are present, but in very small quantity, and there are equal chances that these species came from the Mississippi River basin. Had the Red River been acting as a tributary to the Mississippi River at the time of deposition of these shoals, the pollen signal it presented was surely diluted by the extremely larger input of the Mississippi. Had this been Red River sedimentation in abandoned Mississippi River channels, the pollen signal would surely have included much more arid species and would have been void of species common to northeastern Louisiana which were commonly present. 99% of the species identified are those present in modern open Louisiana coastal marshes/swamps (*Taxodium distichum*, Cyperaceae, Graminae, Chenopodiaceae, Asteraceae), and coastal to upland hardwood forests of the Mississippi alluvial valley (*Pinus*, *Quercus*, *Carya*, *Liquidambar styraciflua*).

CHAPTER 6
CONCLUSIONS

A palynological analysis of the Tiger and Trinity shoals was conducted in order to reconstruct the paleoenvironmental conditions at the time of deposition of the shoals and decipher possible differences in shoal genesis, regarding their provenance and timing.

Pollen signals indicate that Tiger and Trinity shoal sediments were deposited during the same cycle, or over an interval of time when there was no significant climatic change. Samples were dominated by species of pine and low abundances of oak and hickory, indicating that deposition of these shoals possibly postdate a shift in southeastern evergreen taxa in coastal plain forests from oak and hickory-dominated to pine-dominated that occurred at ≈5,000 B.P. (Delcourt, 1980, 1985). This information would imply that these sediments were likely deposited during the Teche (5,500-3,800 B.P.) rather than the Maringouin (7,500-5000 B.P.) delta cyle of the Mississippi River.

Lack of dinoflagellate species and presence of low-salinity tolerant foraminifer species indicate that the deposition of sediments took place in a marine realm characterized by salinity most likely inferior to 15 per mil such as a bay, lagoon, or marsh area.

Ninety nine percent of the pollen species recovered are found today within 100 miles of the mouth of the Mississippi River drainage basin and are typical of those present in modern open Louisiana coastal marshes and swamps (*Taxodium distichum*, Cyperaceae, Graminae, Chenopodiaceae, Asteraceae), and coastal to upland hardwood

forests of the Mississippi alluvial valley (*Pinus*, *Quercus*, *Carya*, *Liquidambar styraciflua*). This assemblage indicates that the main source of organic matter deposited within the shoals originated from an area most likely no further than 100 miles from the river mouth.

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APPENDIX A. PLATES OF KEY PALYNOLOGICAL SPECIES

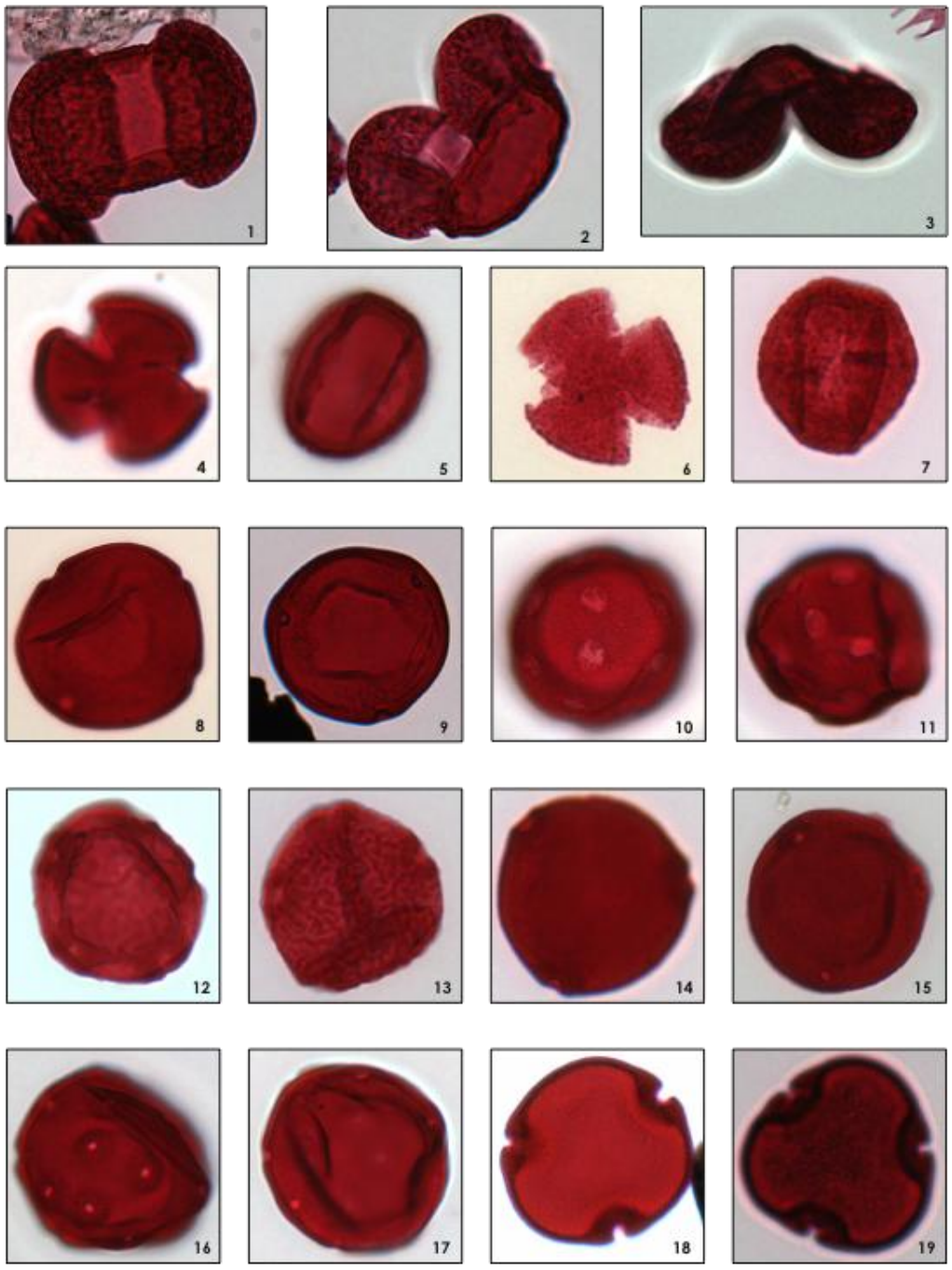


Plate 1. Light photomicrographs of arboreal species. 1-3. *Pinus* spp. 4-7. *Quercus* spp. 8-9. *Carya* spp. 10-11. *Liquidambar styraciflua*. 12-13. *Ulmus americana*. 14-15. *Ostrya virginiana*. 16-17. *Juglans nigra.* 18-19. *Tilia americana*.

Plate 2. Photos of plants represented by arboreal pollen. 1. *Pinus* spp. (USDA plants). 2. *Quercus* spp. (USDA plants). 3. *Carya* spp. (USDA plants). 4. *Liquidambar styraciflua*. (USDA plants).

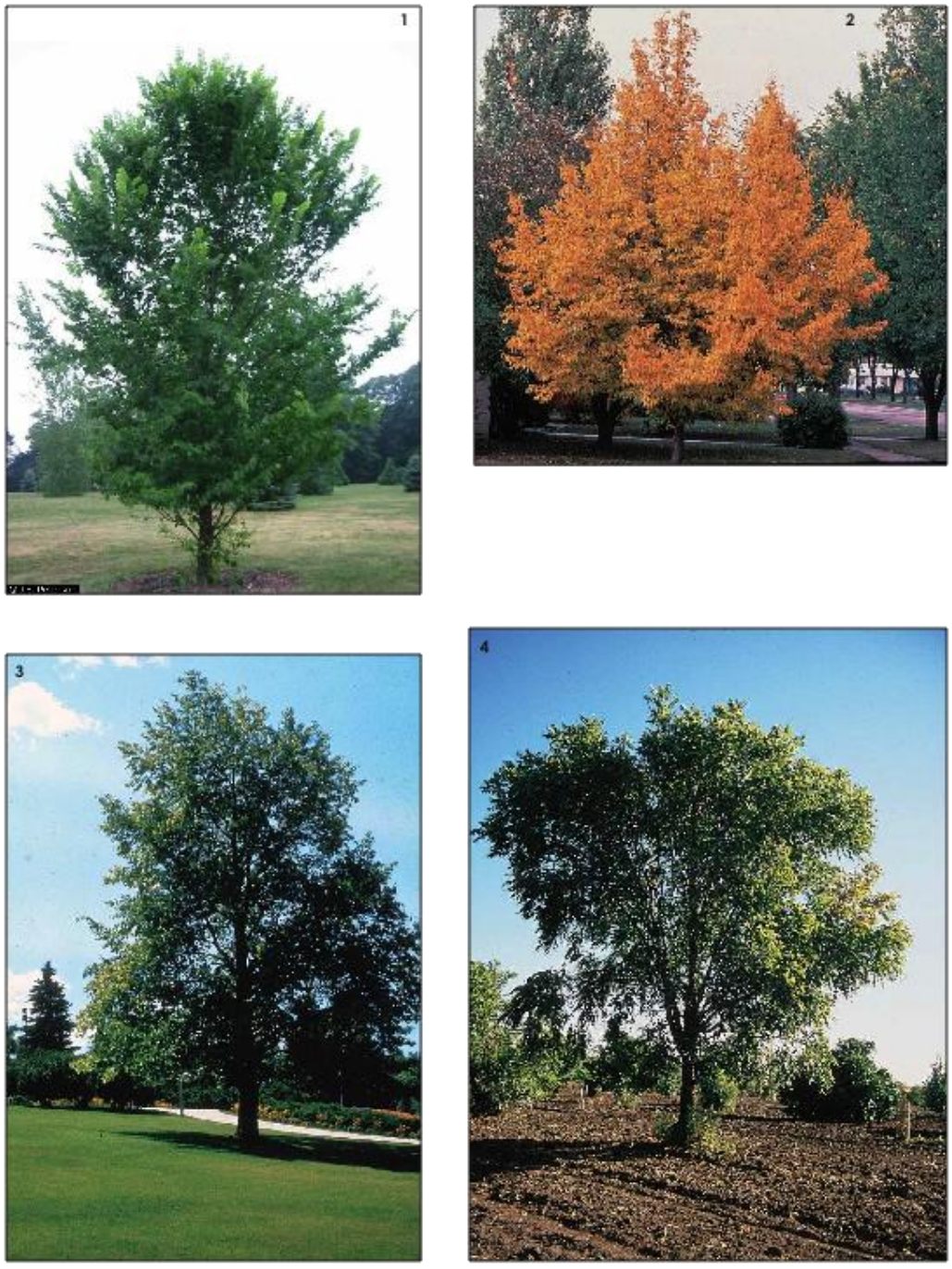


Plate 3. Photos of plants represented by arboreal pollen cont. 1. *Ulmus americana*. (USDA plants). 2. *Ostrya virginiana*. (USDA plants). 3. *Juglans nigra.* (USDA plants). 4. *Tilia americana*. (USDA plants).

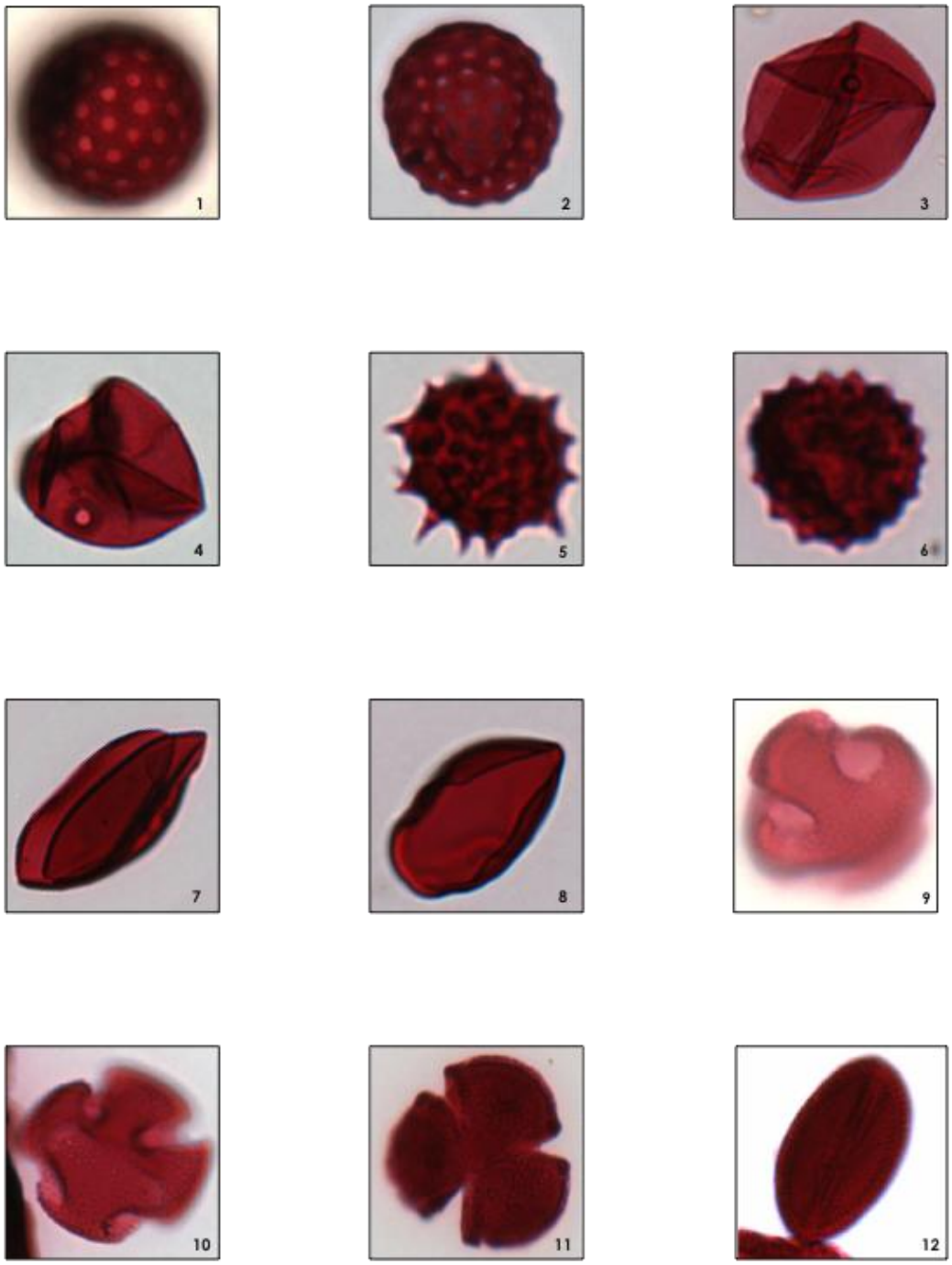


Plate 4. Light photomicrographs of non-arboreal species. 1-2. Chenopodiaceae spp. 3-4. Graminae spp. 5-6. Asteraceae spp. 7-8. Magnoliaceae spp. 9-10. *Ribes curvatum*. 11-12. *Brunicchia ovata*.

Plate 5. Photos of plants represented by non-arboreal pollen counts. 1. Chenopodiaceae spp. (USDA plants). 2. Graminae spp. (USDA plants). 3. Asteraceae spp. (USDA plants). 4. Magnoliaceae spp. (USDA plants). 5. *Ribes curvatum*. (USDA plants). 6. *Brunicchia ovata*. (USDA plants).

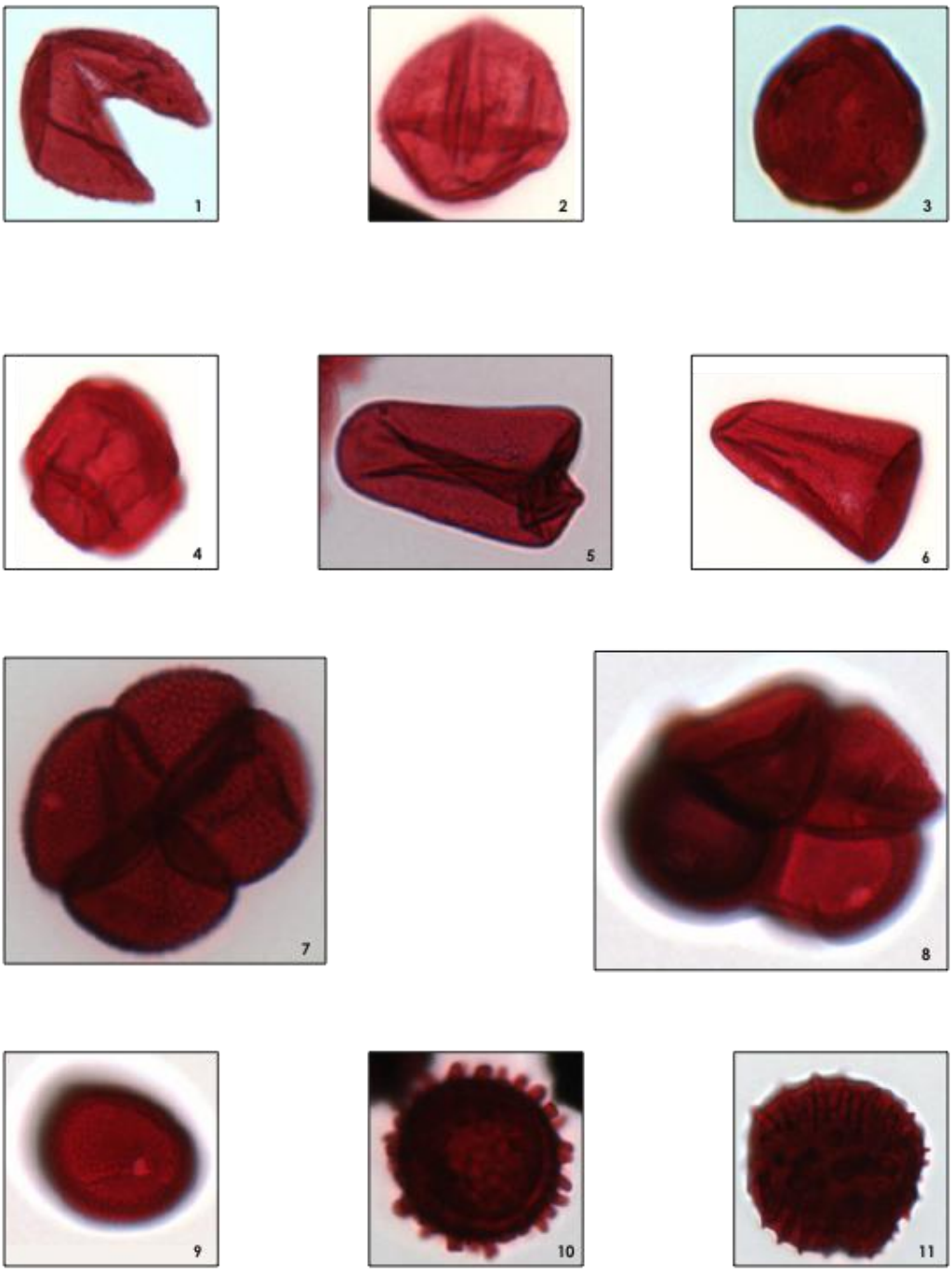


Plate 6. Light photomicrographs of aquatic species. 1-2. *Taxodium distichum*. 3-4. *Planera aquatica*. 5-6. Cyperaceae spp. 7-9. *Typha latifolia*. 10-11. *Nymphaea odorata*.

Plate 7. Photos of plants represented by aquatic pollen counts. 1. *Taxodium distichum*. (USDA plants). 2. *Planera aquatica*. (USDA plants). 3. Cyperaceae spp. (USDA plants). 4. *Typha latifolia*. (USDA plants). 5. *Nymphaea odorata*. (USDA plants).

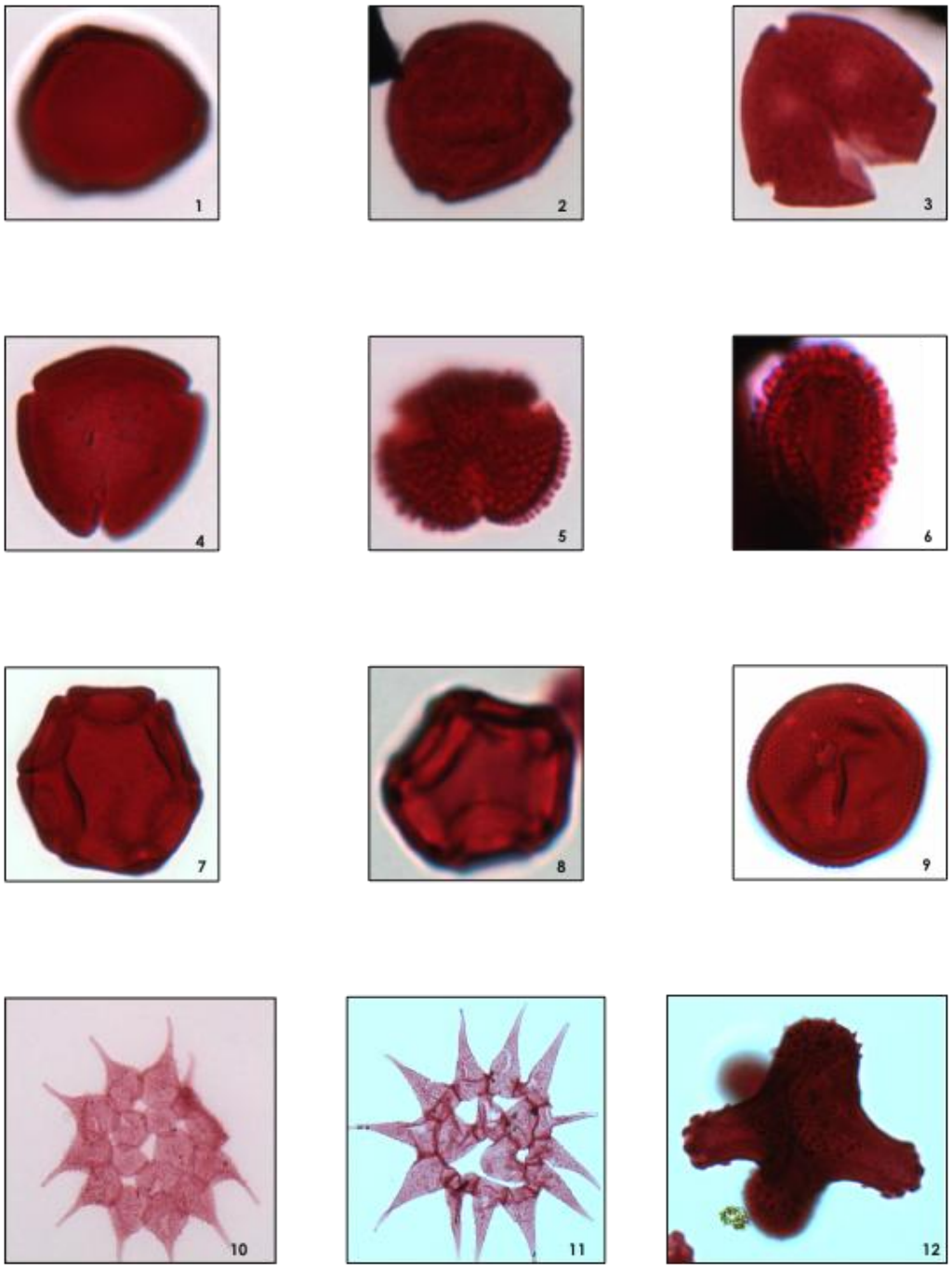


Plate 8. Light photomicrographs of Shrub, freshwater, and reworked species. 1-2. *Myrica heterophylla.* 3-4. *Myrica inodora.* 5-6. *Ilex glabra*. 7-8. *Alnus serrulata*. 9. *Tasmanites*. 10-11. *Pediastrum* spp. 12. *Aquilapollenites* sp.



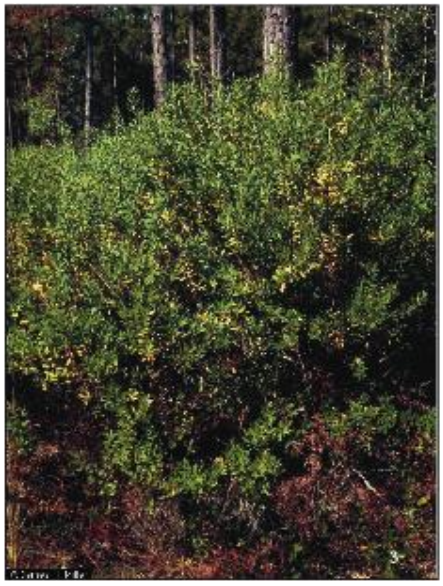
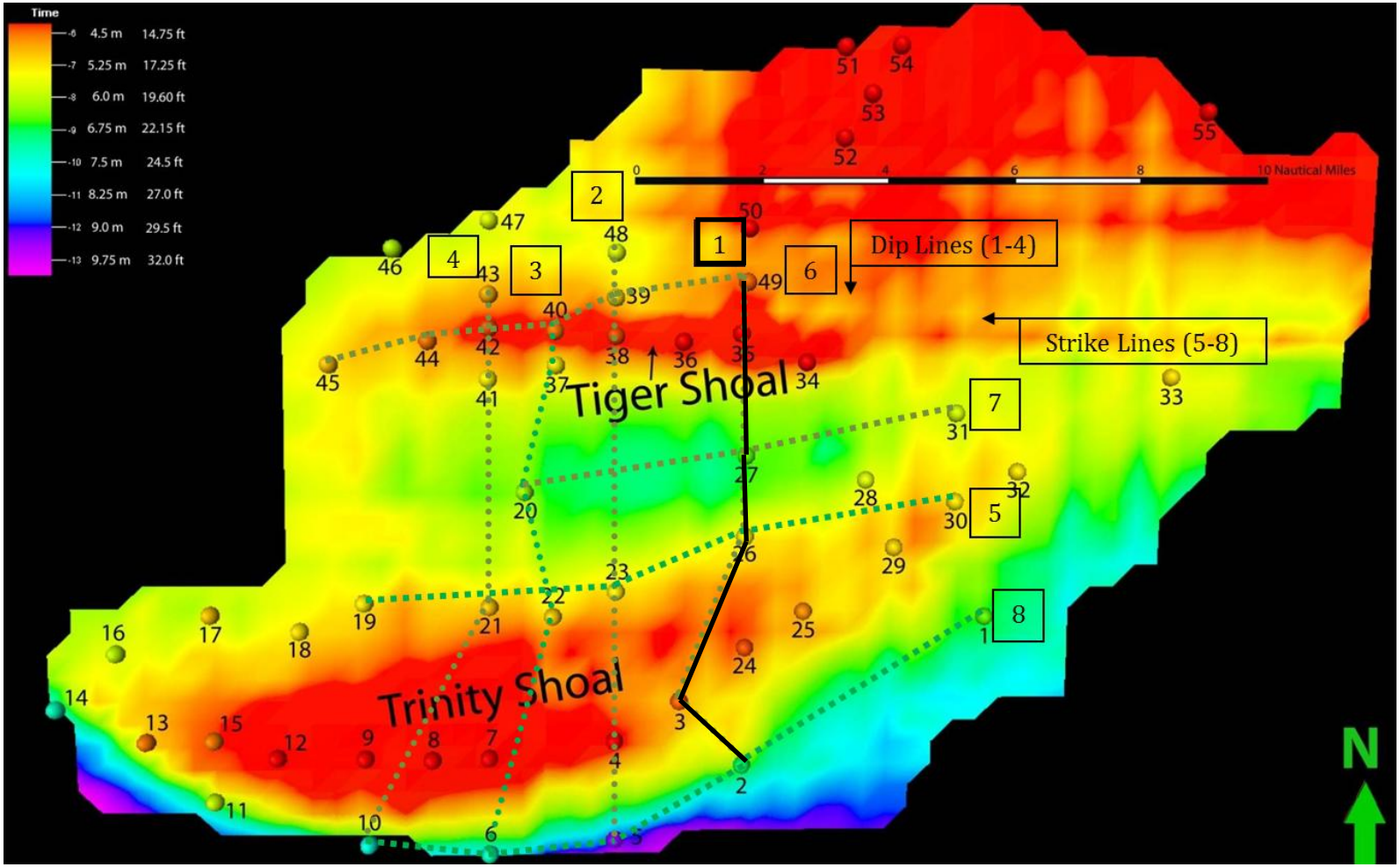


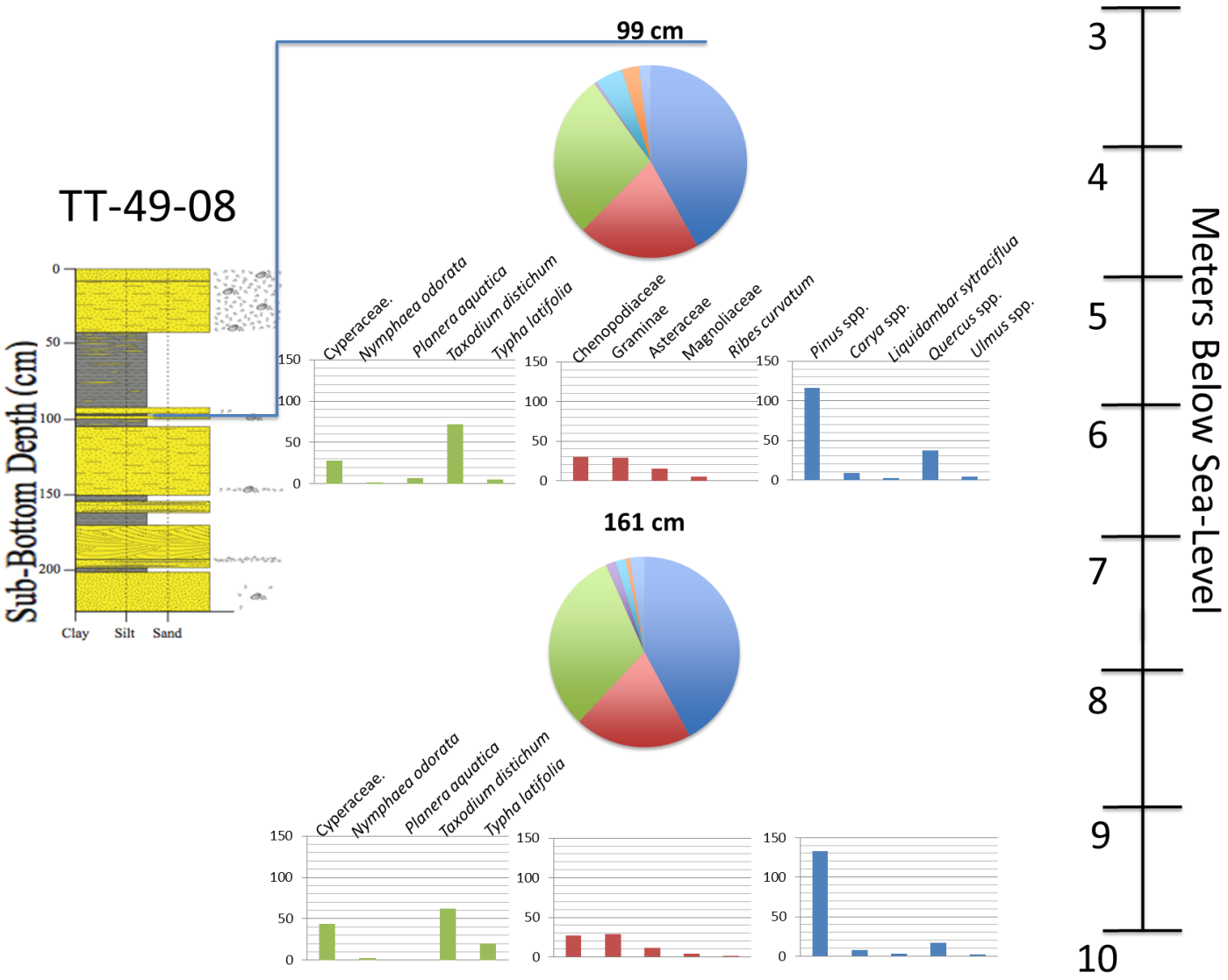

Plate 9. Photos of plants represented by shrub pollen counts. 1. *Myrica heterophylla.* (USDA plants). 2. *Myrica inodora.* (USDA plants). 3. *Ilex glabra*. (USDA plants). 4. *Alnus serrulata*. (USDA plants).

APPENDIX B. STRIKE AND DIP TRANSECTS OF POLLEN COUNTS AND ASSEMBLAGES (LINES 1-8)

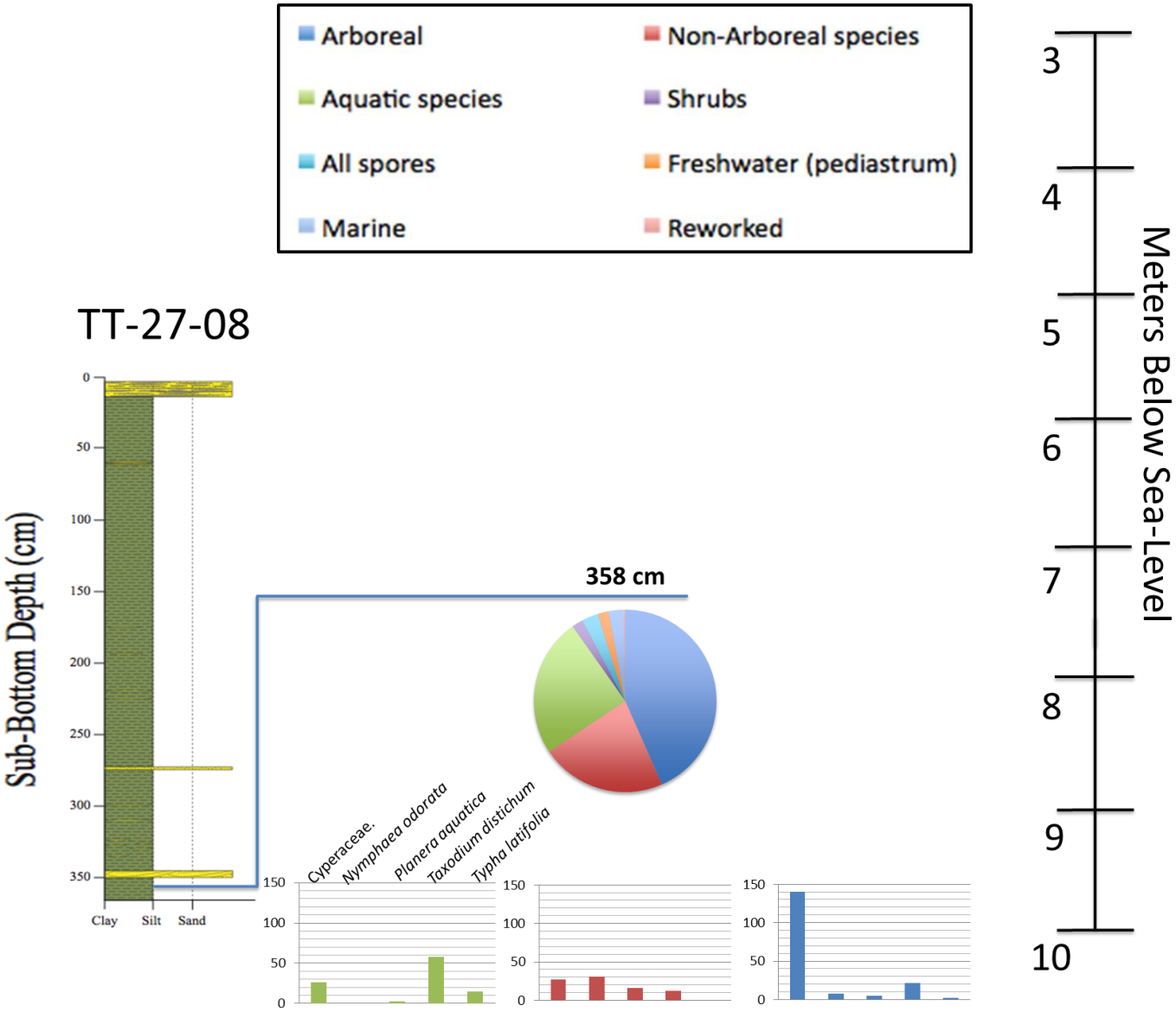


Map of Line 1

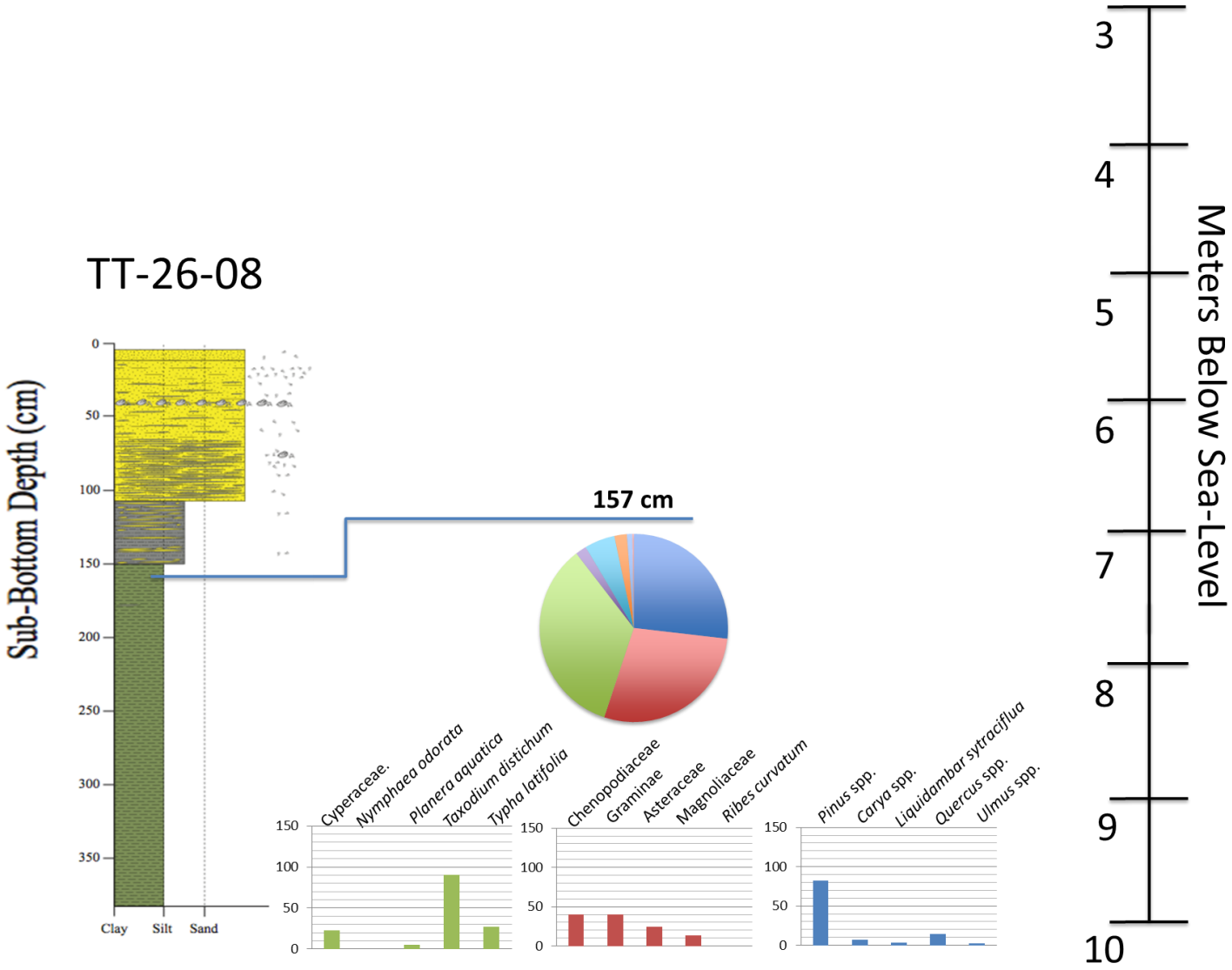
Line 1
N>S


TT-49-08
Sub-Bottom Depth (cm)
0
50
100
150
200
Clay
Silt
Sand
99 cm
Cyperaceae.
Nymphaea odorata
Planera aquatica
Taxodium distichum
Typha latifolia
Chenopodiaceae
Gramineae
Asteraceae
Magnoliaceae
Ribes curvatum
Pinus spp.
Carya spp.
Liquidambar sytraciflua
Quercus spp.
Ulmus spp.
161 cm
Meters Below Sea-Level
3
4
5
6
7
8
9
10

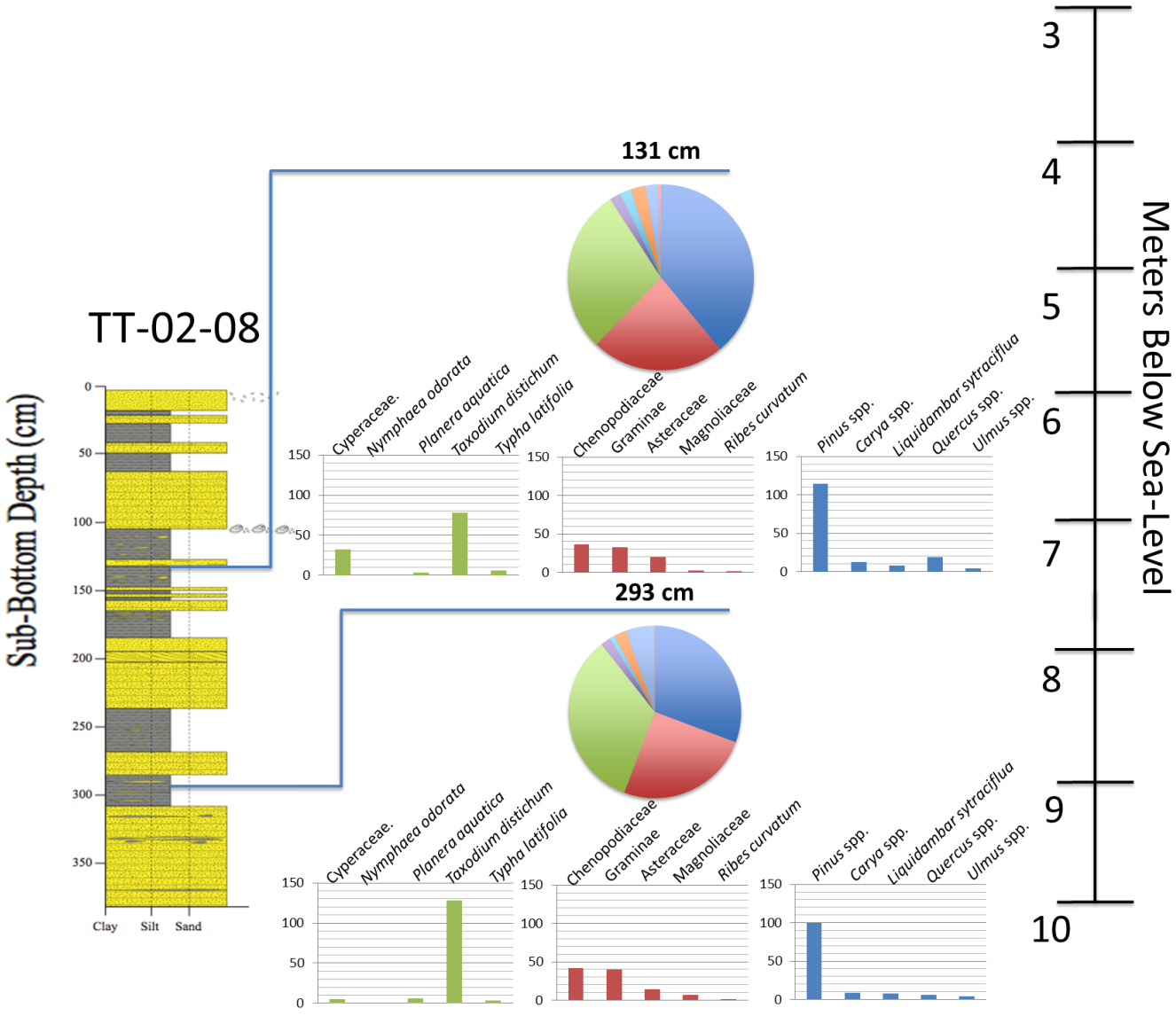
Line 1 Cont.
N>S

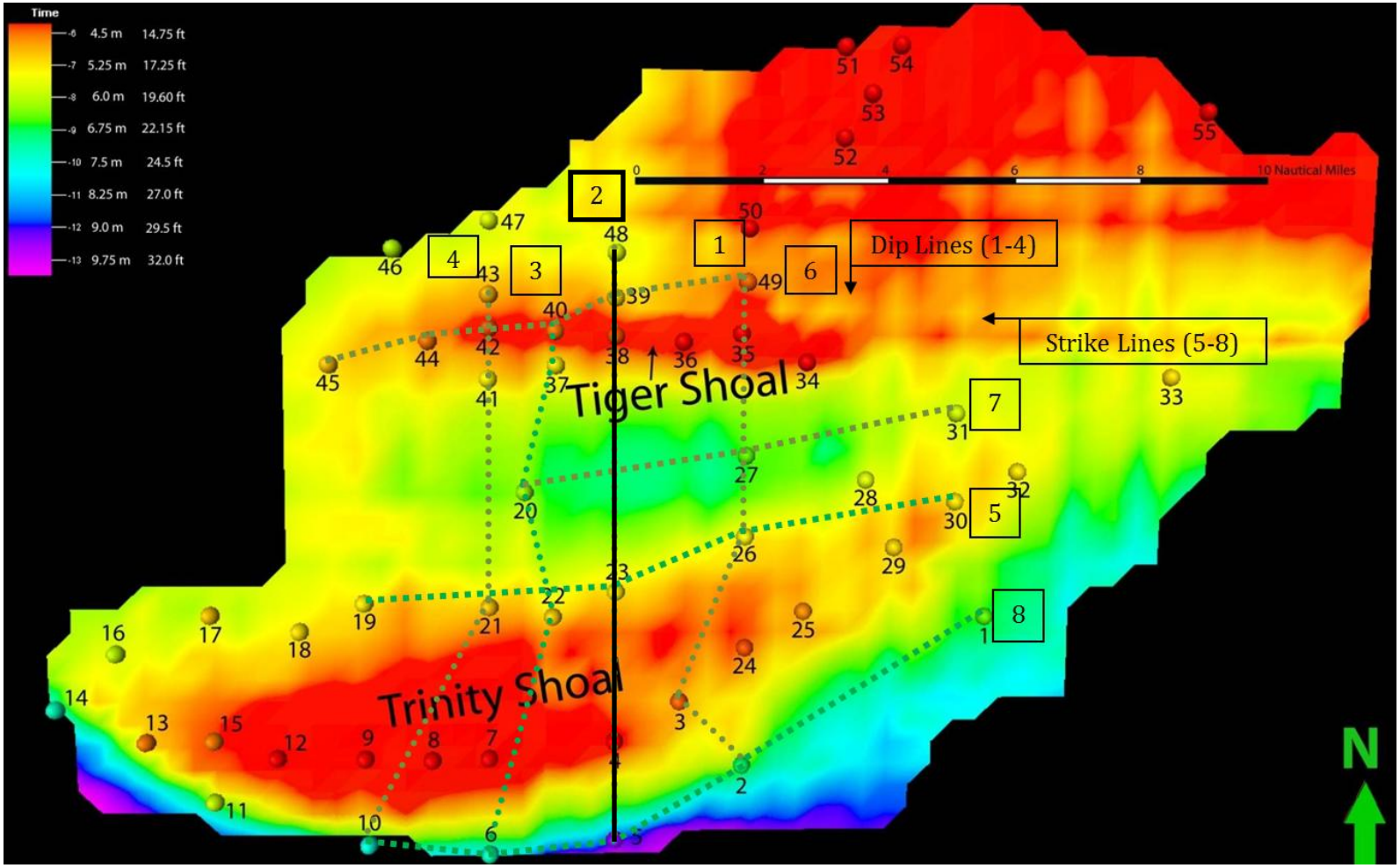


Line 1 Cont.
N>S



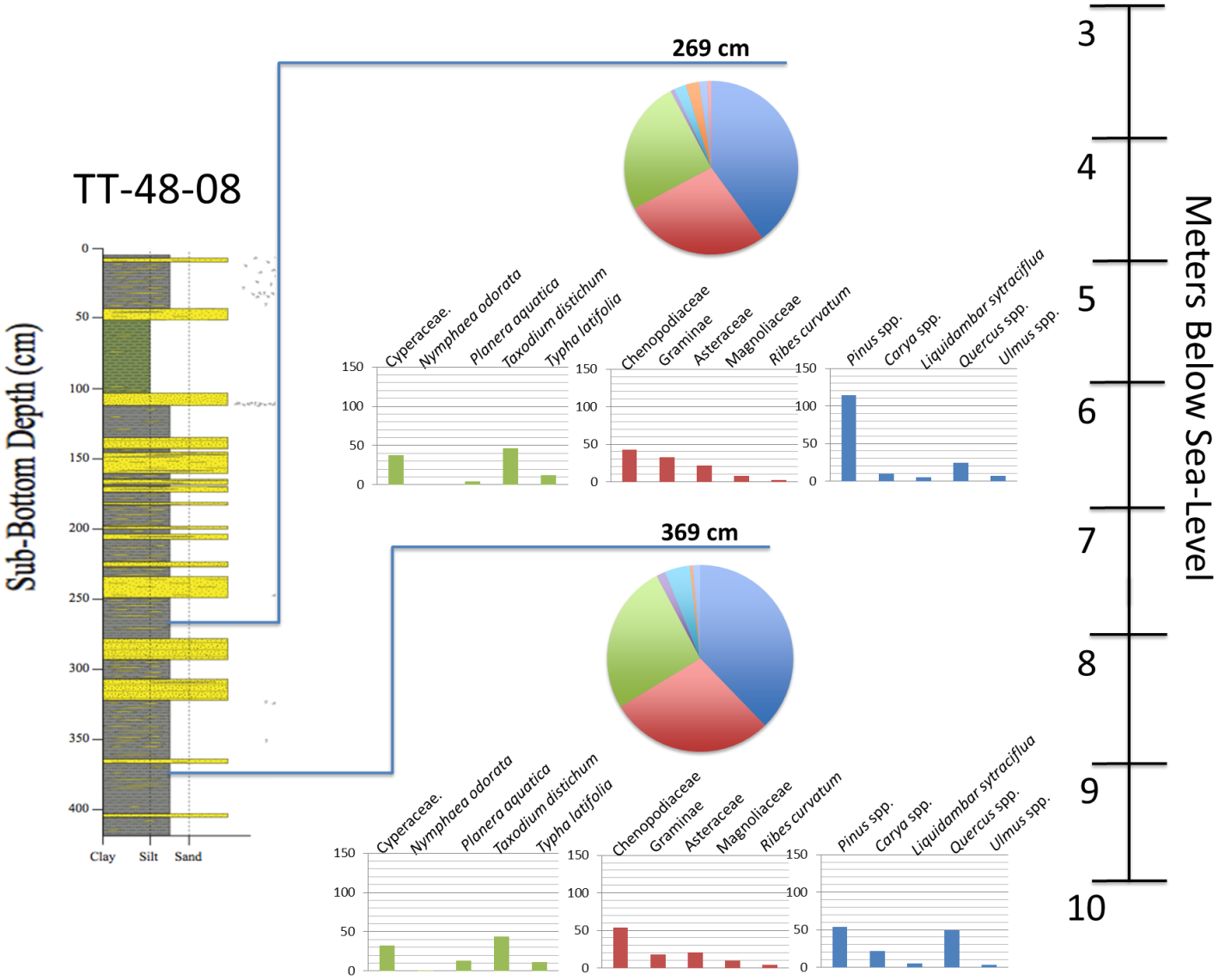
Line 1 Cont.
N>S



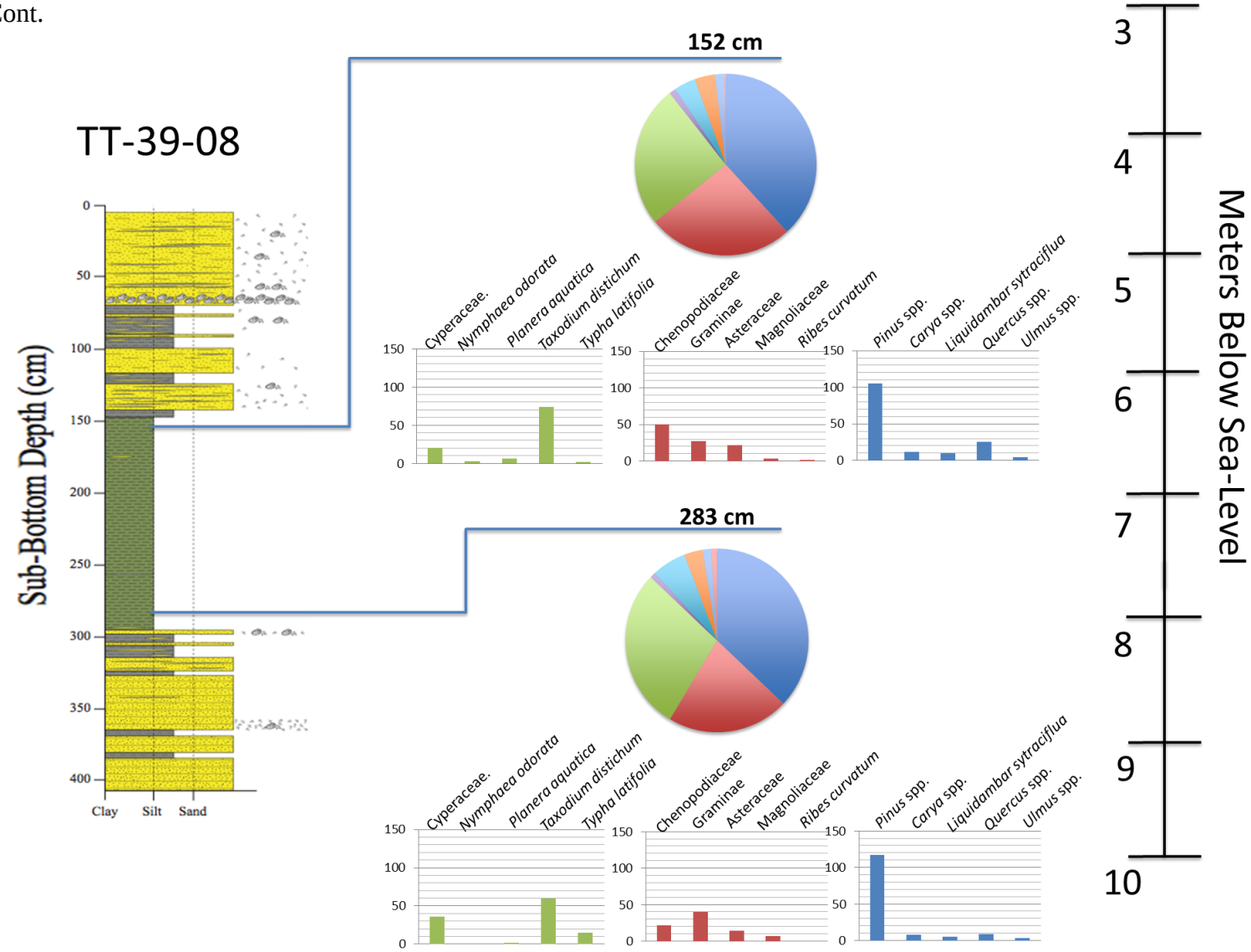

Time
-6 4.5 m 14.75 ft
-7 5.25 m 17.25 ft
-8 6.0 m 19.60 ft
-9 6.75 m 22.15 ft
-10 7.5 m 24.5 ft
-11 8.25 m 27.0 ft
-12 9.0 m 29.5 ft
-13 9.75 m 32.0 ft
0 2 4 6 8 10 Nautical Miles
Dip Lines (1-4)
Strike Lines (5-8)
Tiger Shoal
Trinity Shoal
1
2
3
4
5
6
7
8
N

Map of Line 2

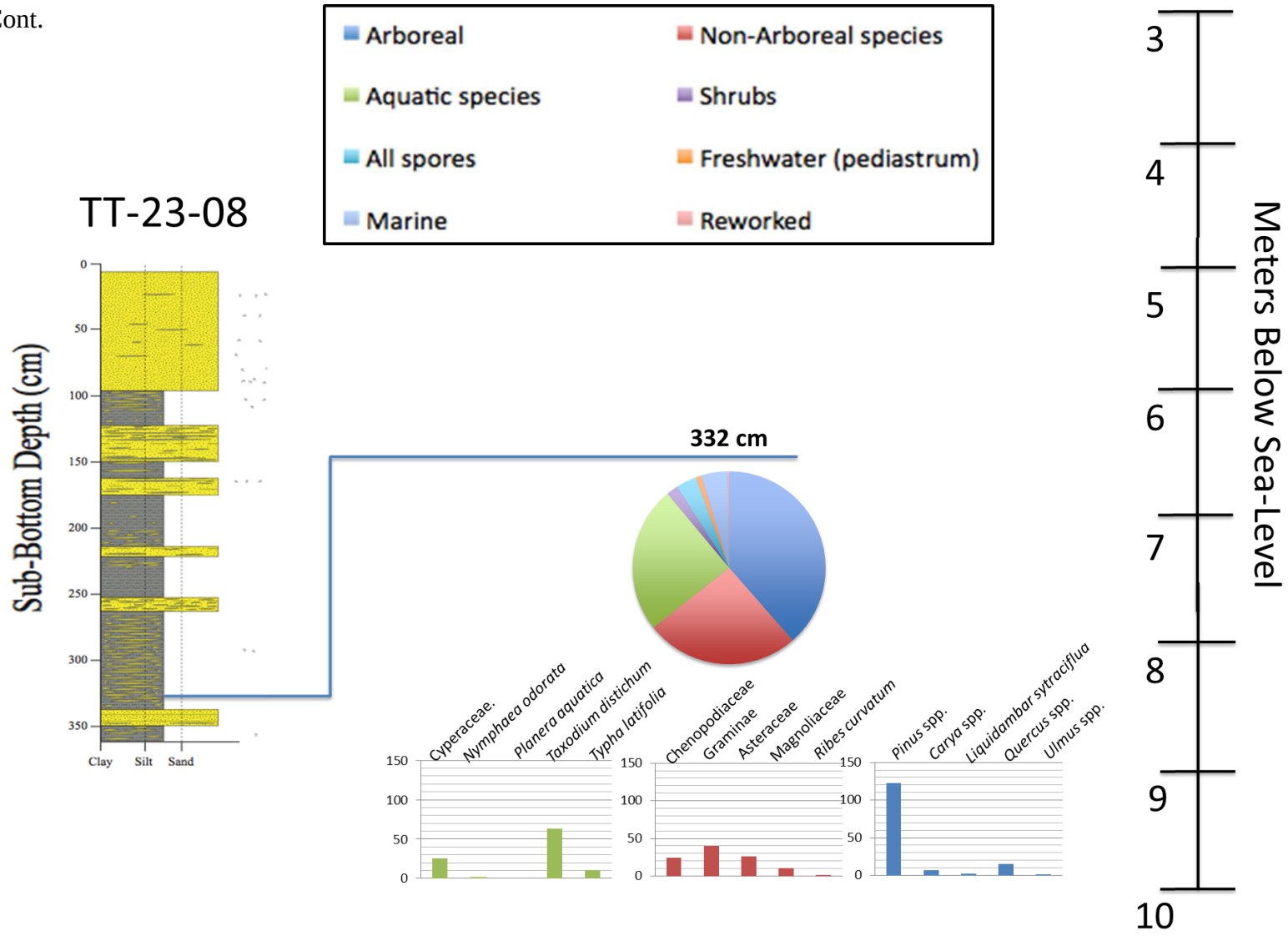
Line 2
N>S


TT-48-08
Sub-Bottom Depth (cm)
0
50
100
150
200
250
300
350
400
Clay
Silt
Sand
269 cm
369 cm
Cyperaceae.
Nymphaea odorata
Planera aquatica
Taxodium distichum
Typha latifolia
Chenopodiaceae
Graminae
Asteraceae
Magnoliaceae
Ribes curvatum
Pinus spp.
Carya spp.
Liquidambar sytraciflua
Quercus spp.
Ulmus spp.
150
100
50
0
3
4
5
6
7
8
9
10
Meters Below Sea-Level

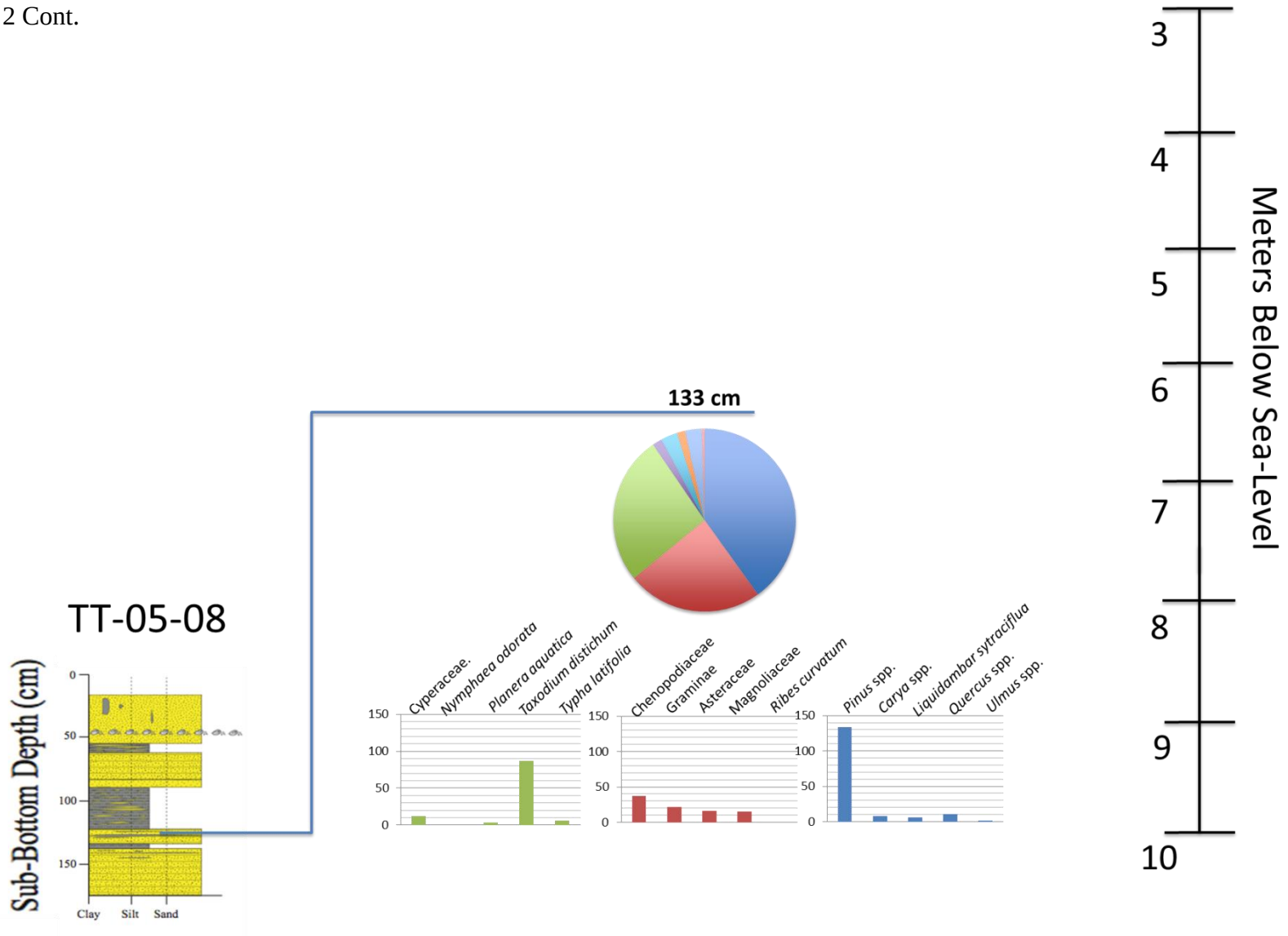
Line 2 Cont.
N>S

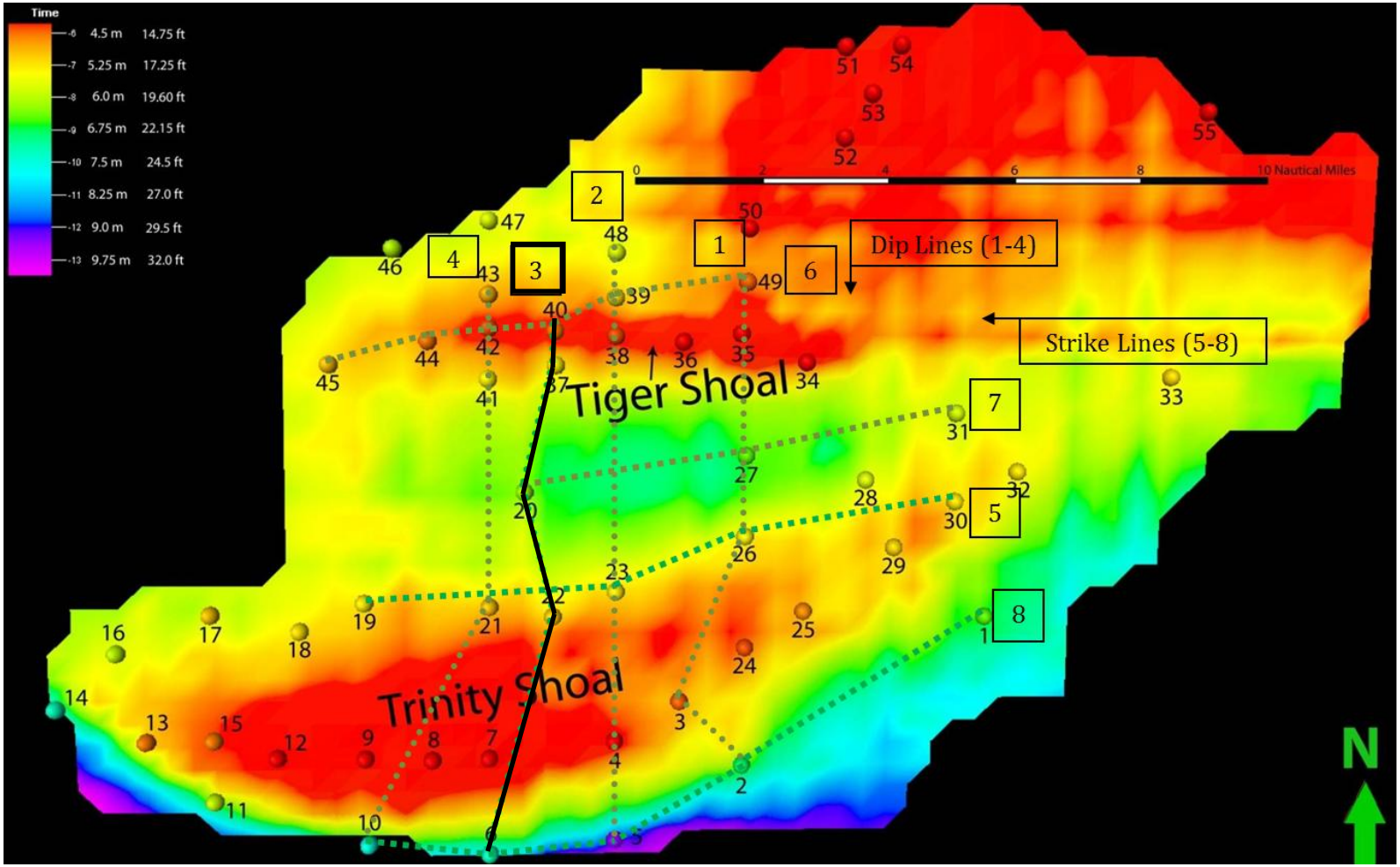


Line 2 Cont.
N>S



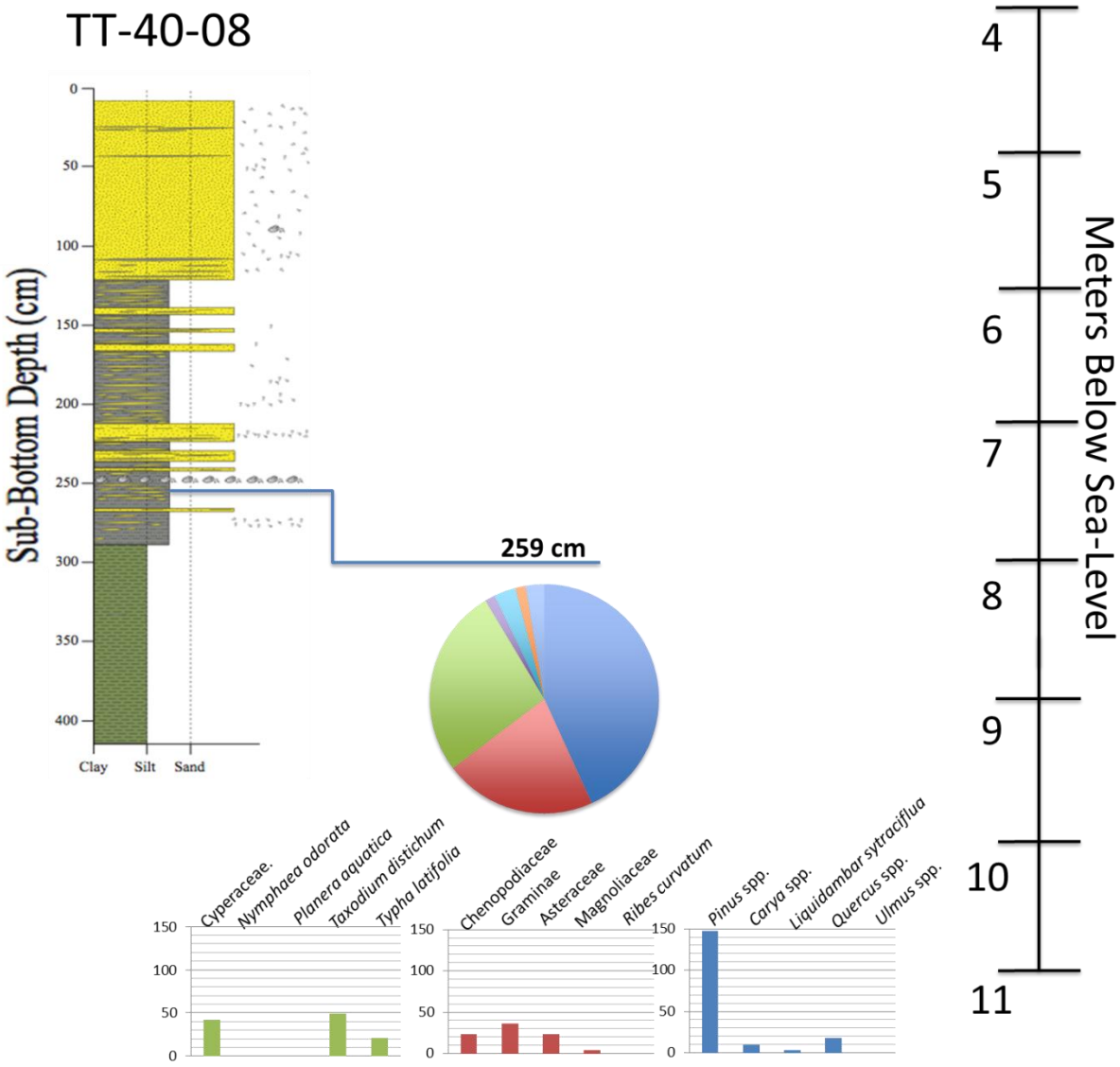
Line 2 Cont.
N>S



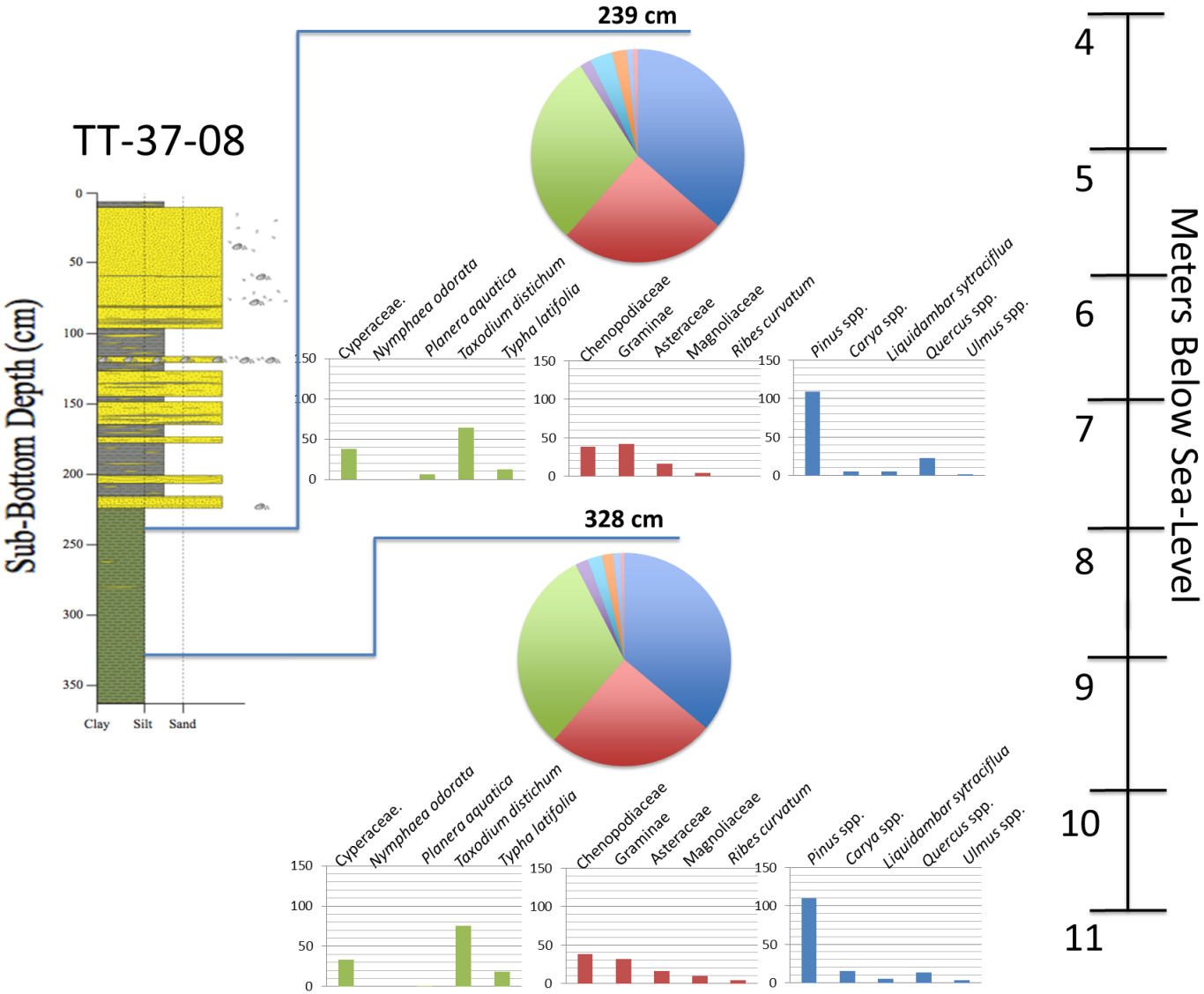

Time
-6 4.5 m 14.75 ft
-7 5.25 m 17.25 ft
-8 6.0 m 19.60 ft
-9 6.75 m 22.15 ft
-10 7.5 m 24.5 ft
-11 8.25 m 27.0 ft
-12 9.0 m 29.5 ft
-13 9.75 m 32.0 ft
0 2 4 6 8 10 Nautical Miles
Dip Lines (1-4)
Strike Lines (5-8)
Tiger Shoal
Trinity Shoal
N
1
2
3
4
5
6
7
8

Map of Line 3

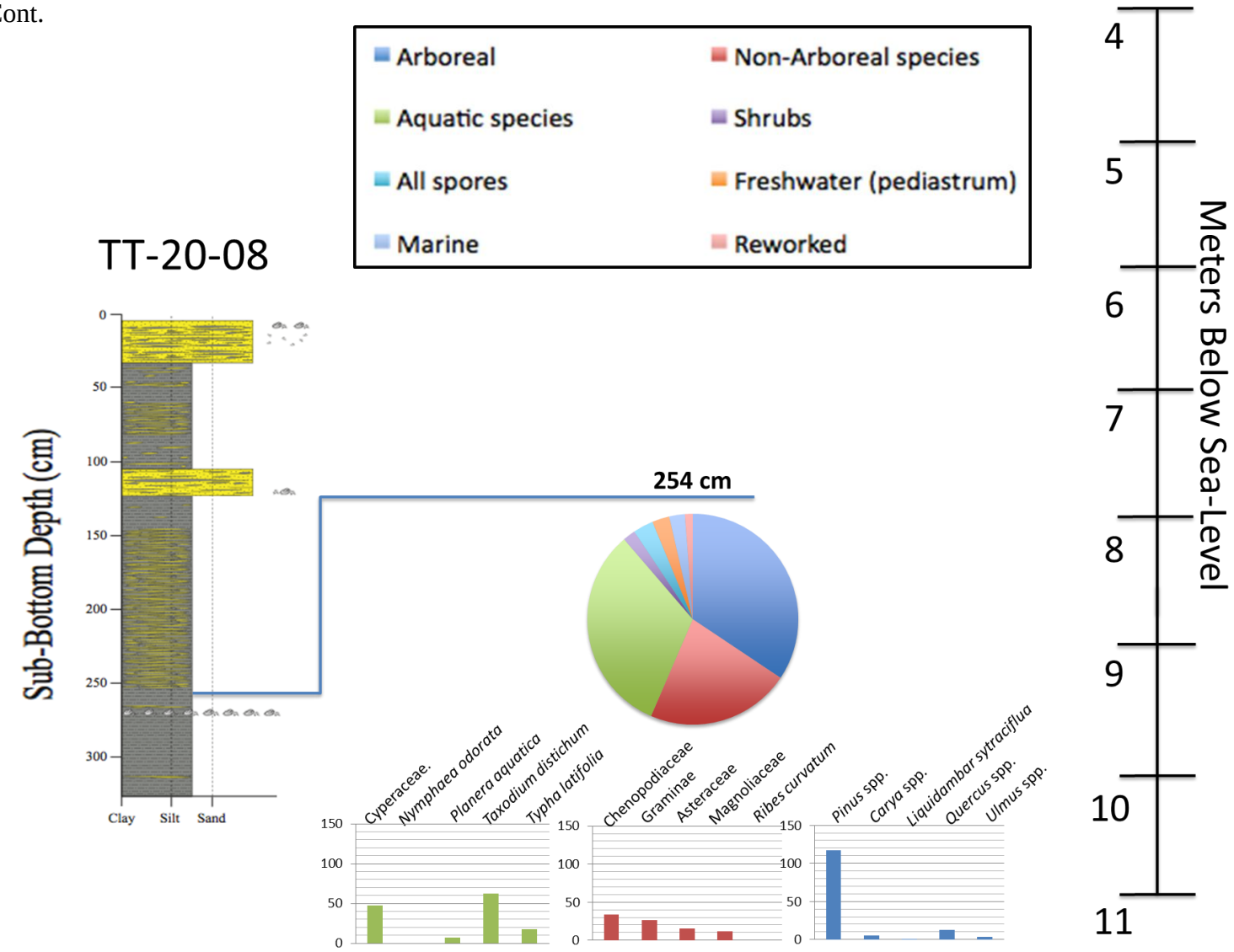
Line 3
N>S


TT-40-08
Sub-Bottom Depth (cm)
0
50
100
150
200
250
300
350
400
Clay
Silt
Sand
259 cm
Cyperaceae.
Nymphaea odorata
Planera aquatica
Taxodium distichum
Typha latifolia
Chenopodiaceae
Graminae
Asteraceae
Magnoliaceae
Ribes curvatum
Pinus spp.
Carya spp.
Liquidambar sytraciflua
Quercus spp.
Ulmus spp.
150
100
50
0
4
5
6
7
8
9
10
11
Meters Below Sea-Level

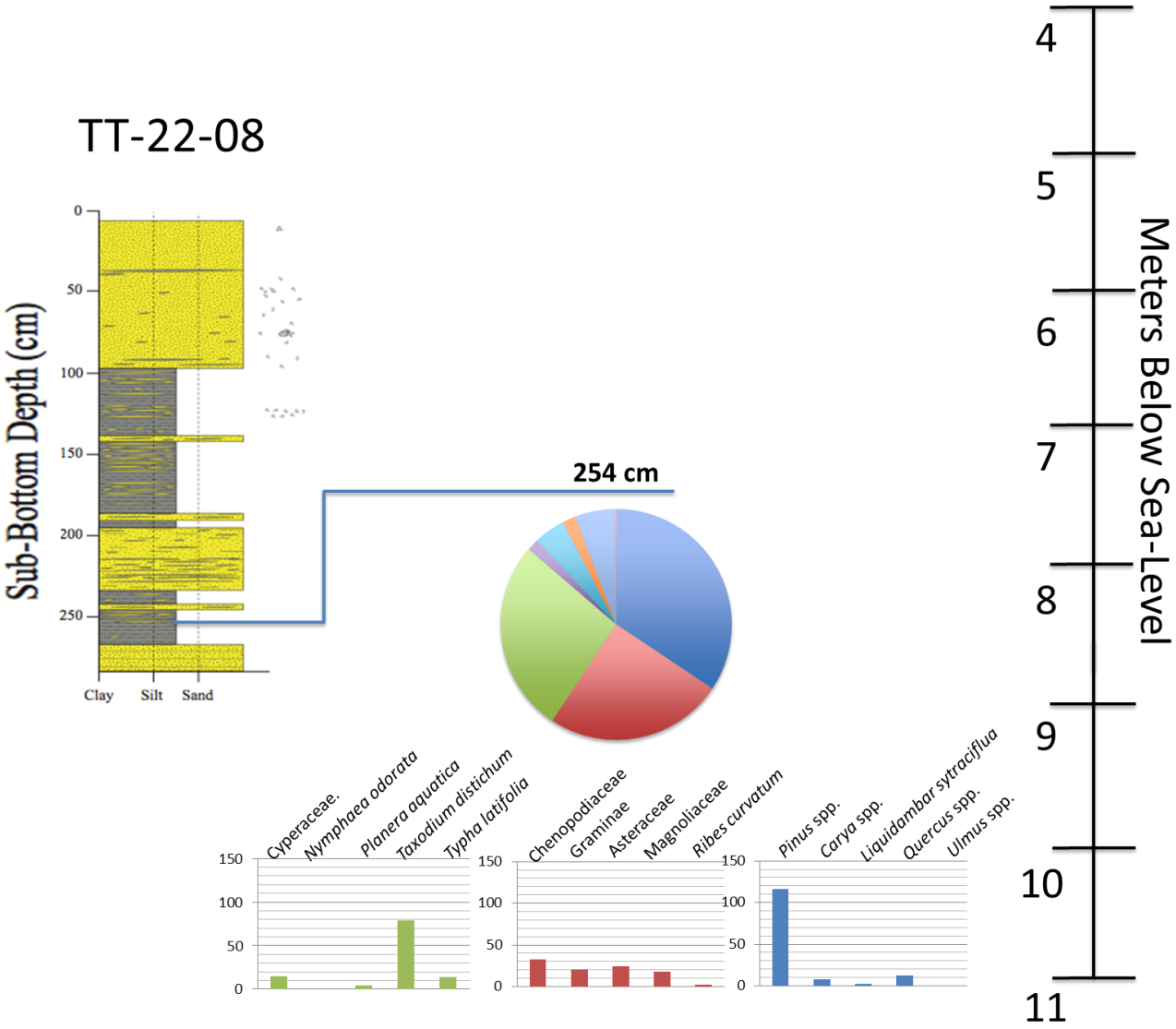
Line 3 Cont.
N>S



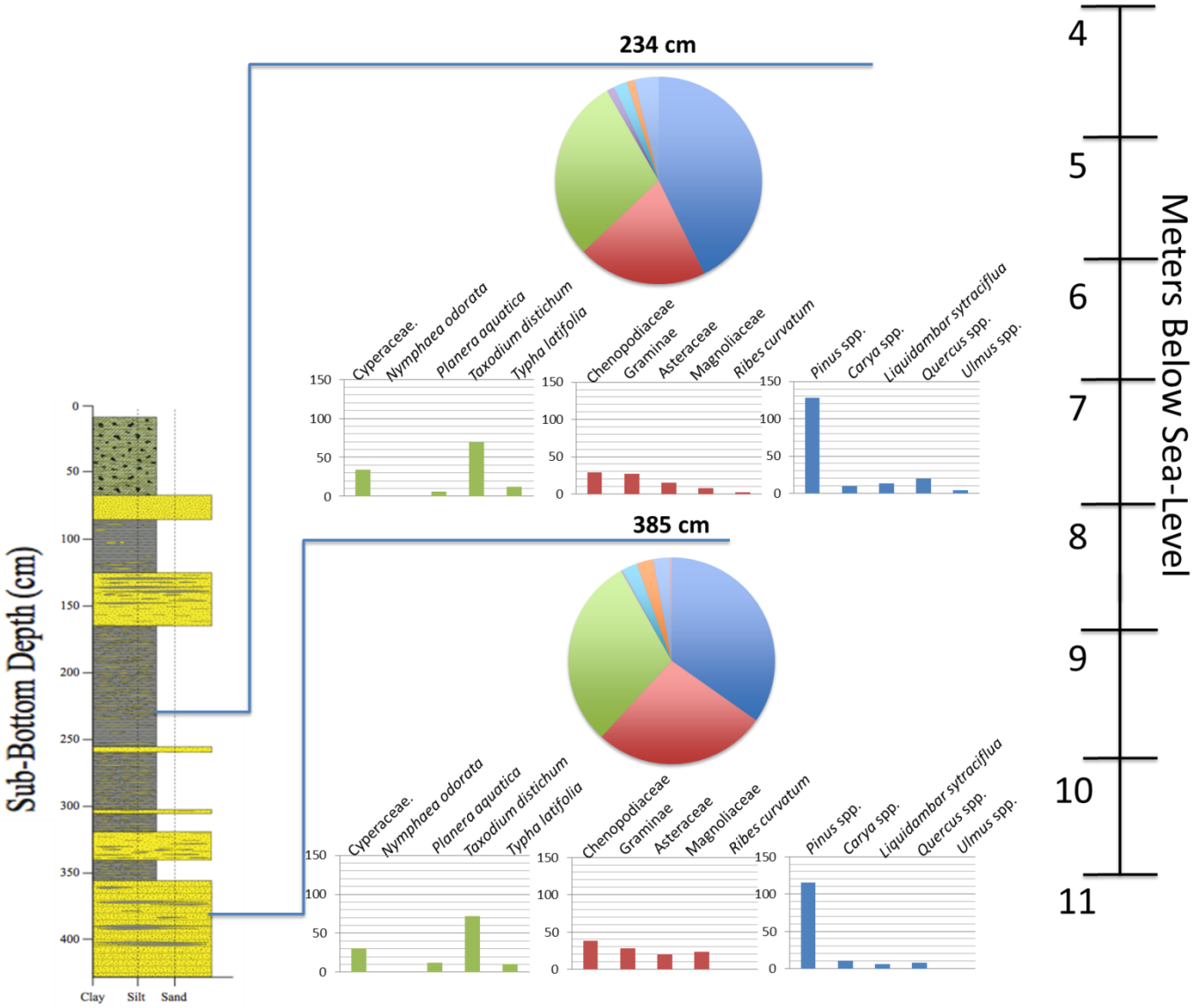
Line 3 Cont.
N>S

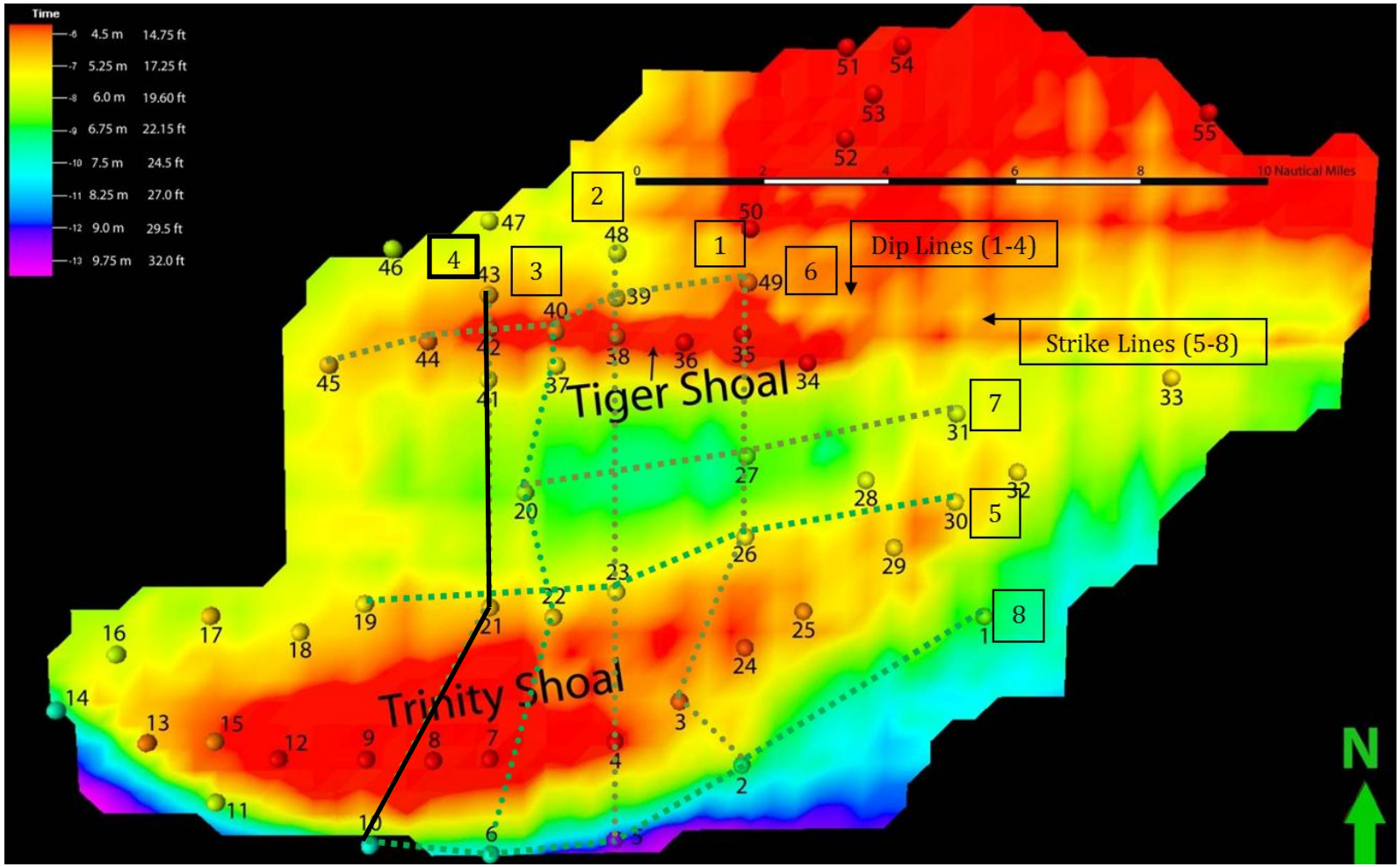


Line 3 Cont.
N>S



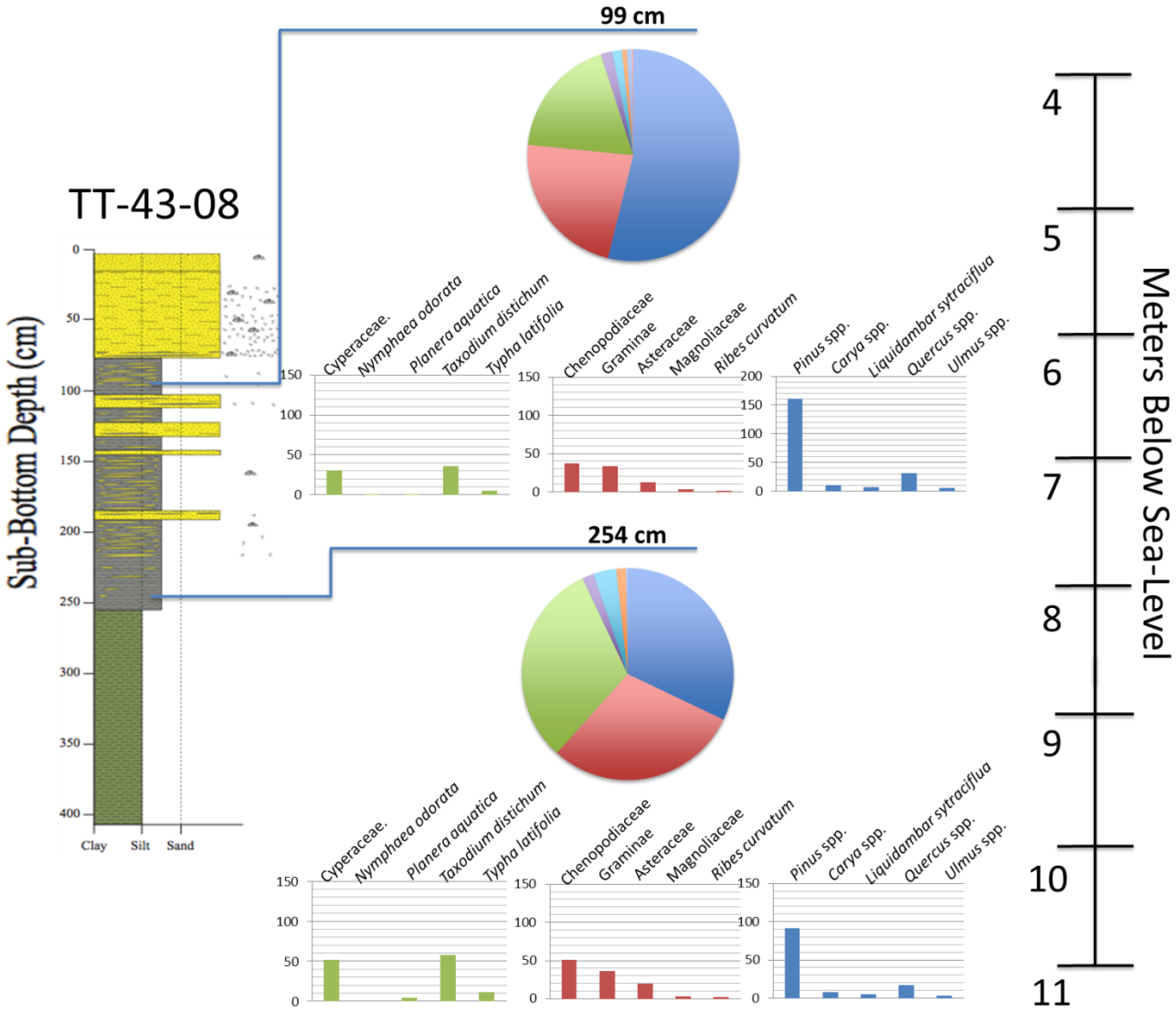
Line 3 Cont.
N>S



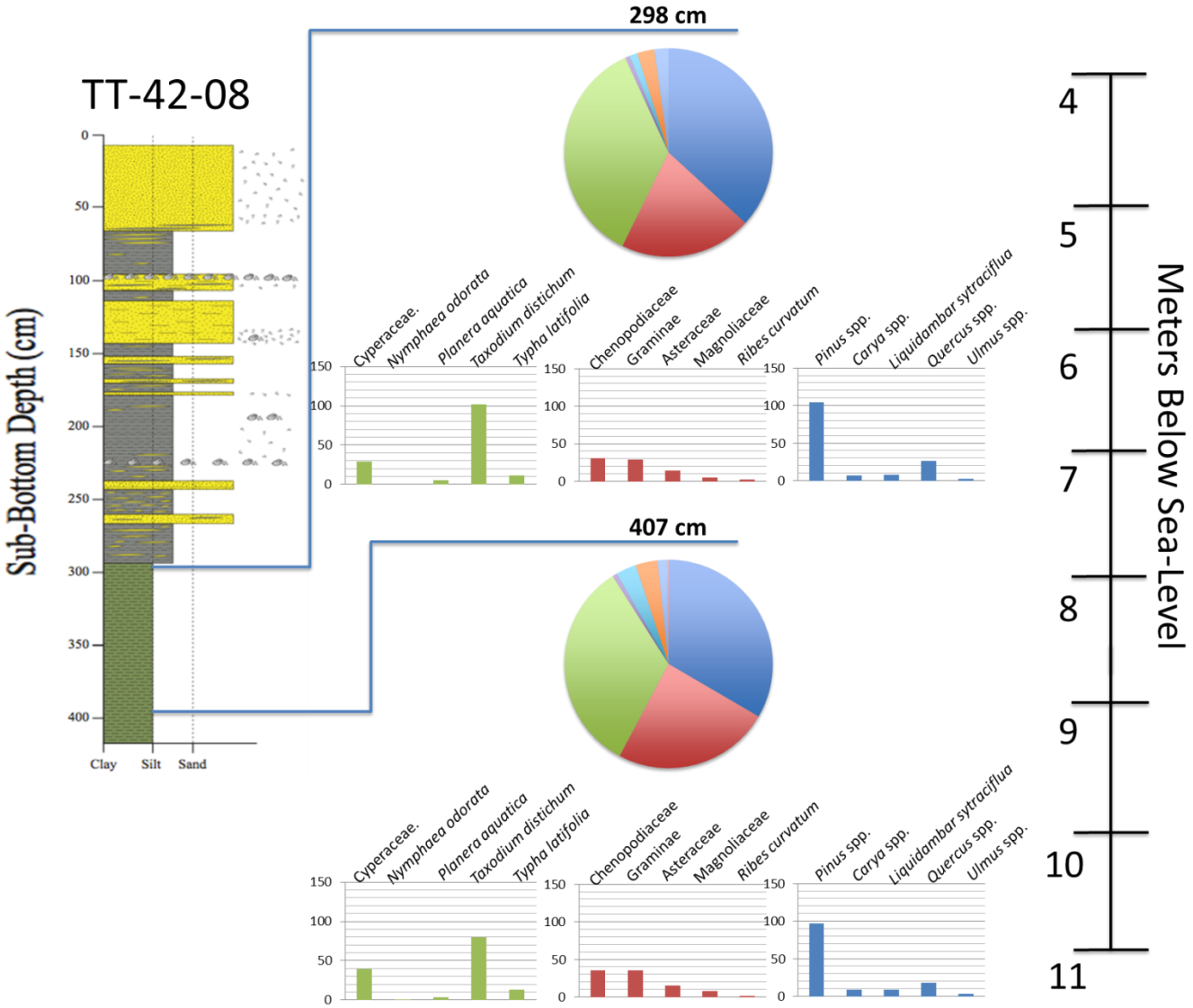

Time
-6 4.5 m 14.75 ft
-7 5.25 m 17.25 ft
-8 6.0 m 19.60 ft
-9 6.75 m 22.15 ft
-10 7.5 m 24.5 ft
-11 8.25 m 27.0 ft
-12 9.0 m 29.5 ft
-13 9.75 m 32.0 ft
0 2 4 6 8 10 Nautical Miles
Dip Lines (1-4)
Strike Lines (5-8)
Tiger Shoal
Trinity Shoal
N

Map of Line 4

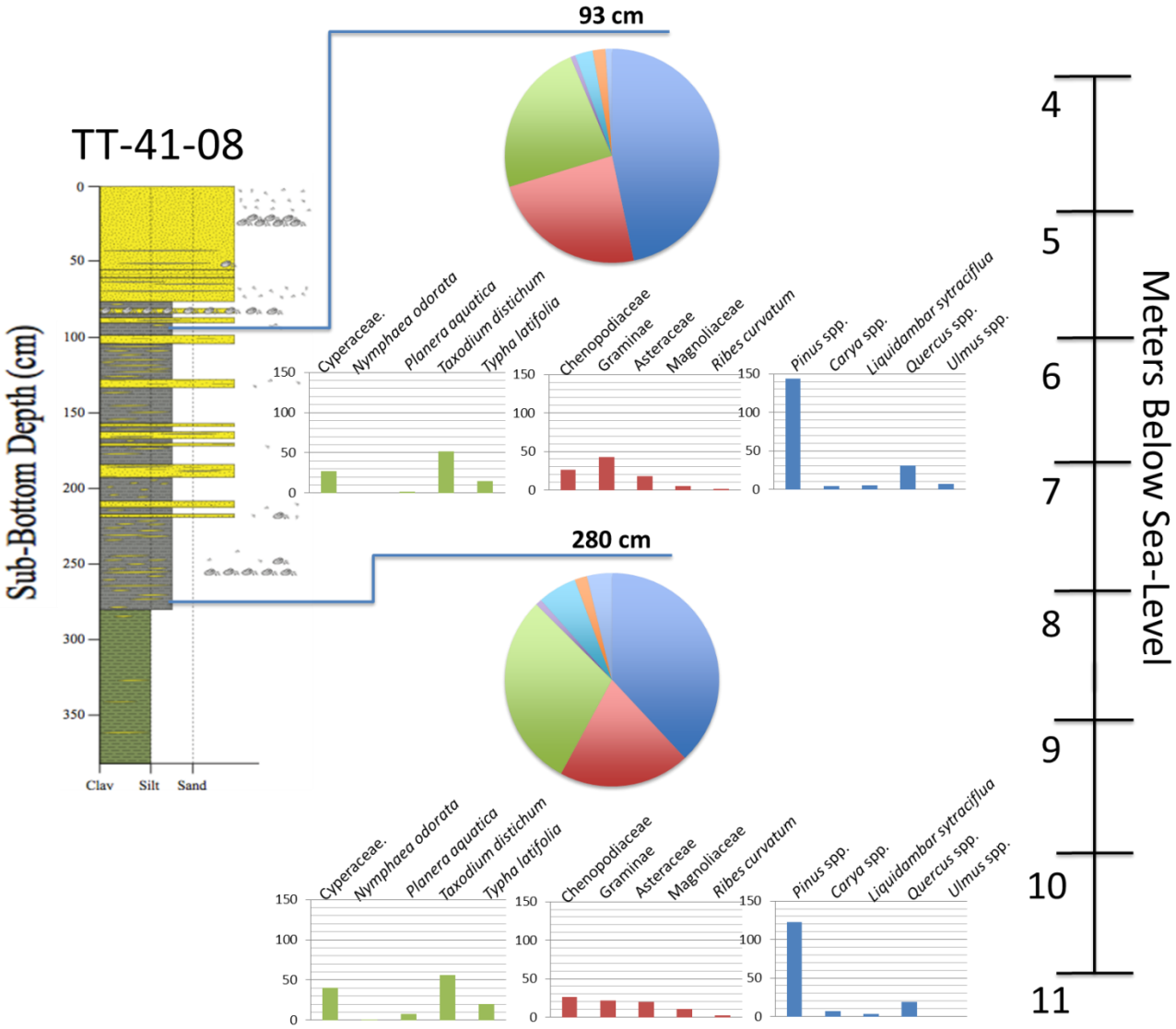
Line 4
N>S


TT-43-08
Sub-Bottom Depth (cm)
0
50
100
150
200
250
300
350
400
Clay
Silt
Sand
99 cm
254 cm
Cyperaceae.
Nymphaea odorata
Planera aquatica
Taxodium distichum
Typha latifolia
Chenopodiaceae
Graminae
Asteraceae
Magnoliaceae
Ribes curvatum
Pinus spp.
Carya spp.
Liquidambar sytraciflua
Quercus spp.
Ulmus spp.
Meters Below Sea-Level
4
5
6
7
8
9
10
11

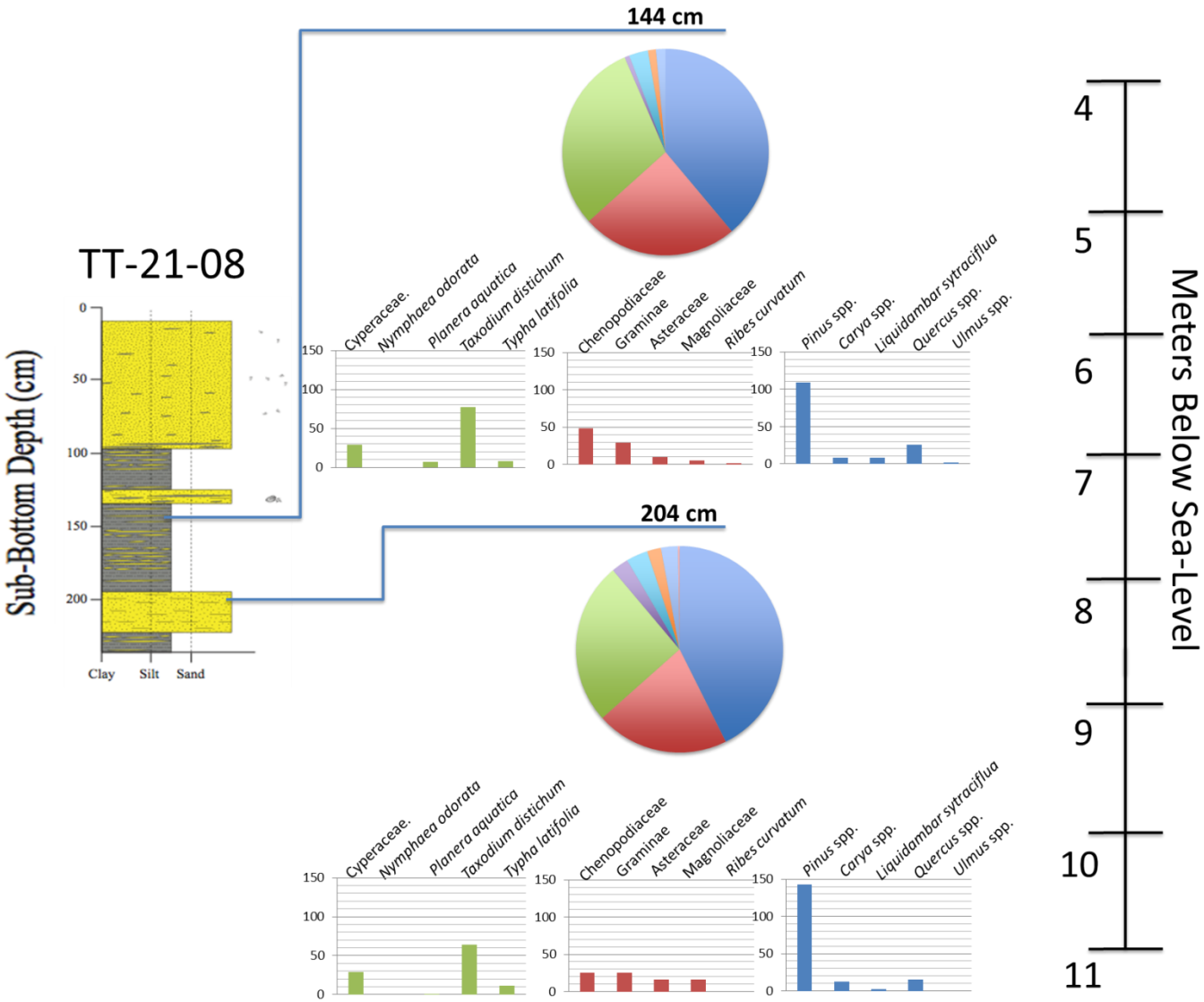
Line 4 Cont.
N>S



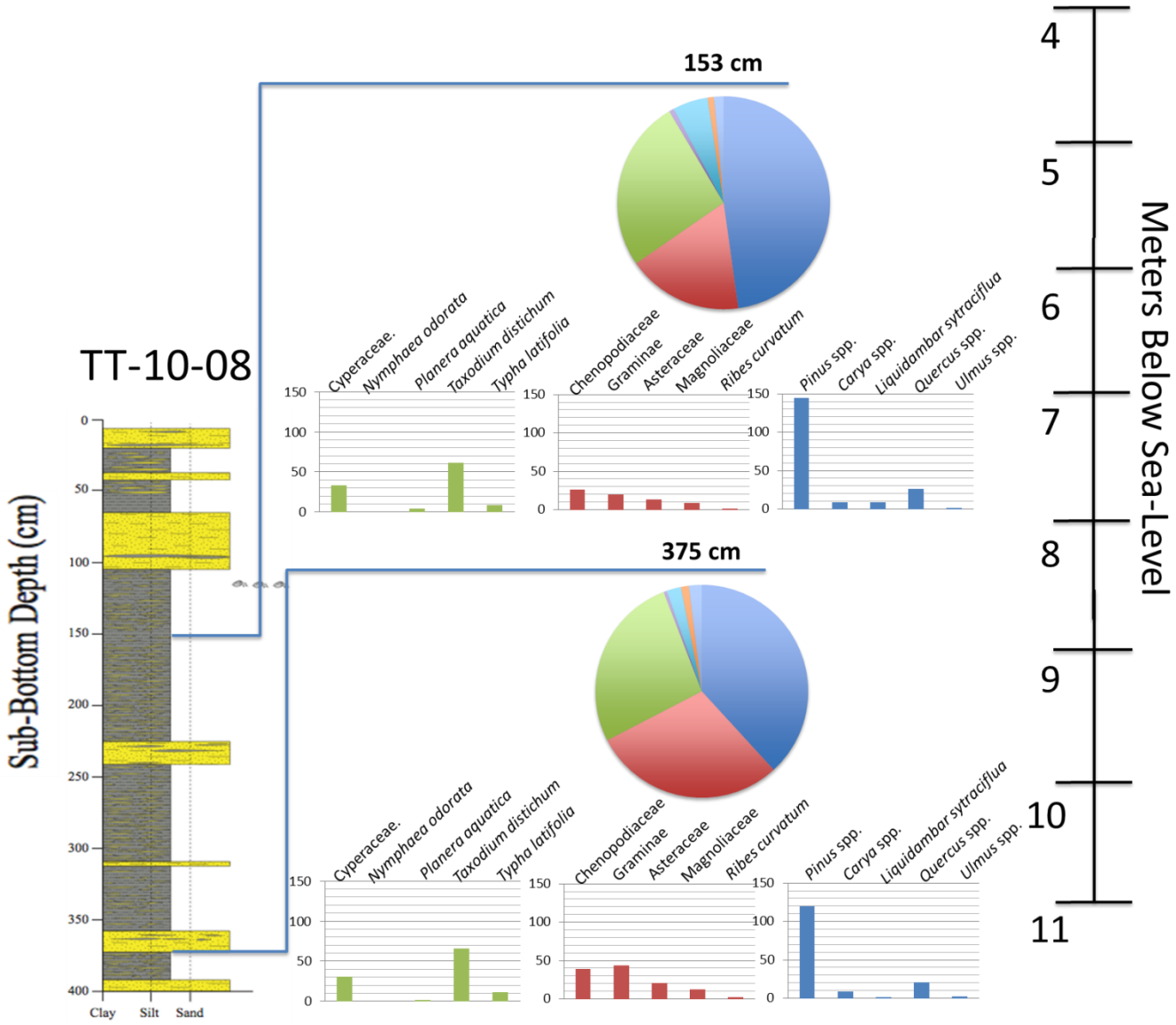
Line 4 Cont.
N>S

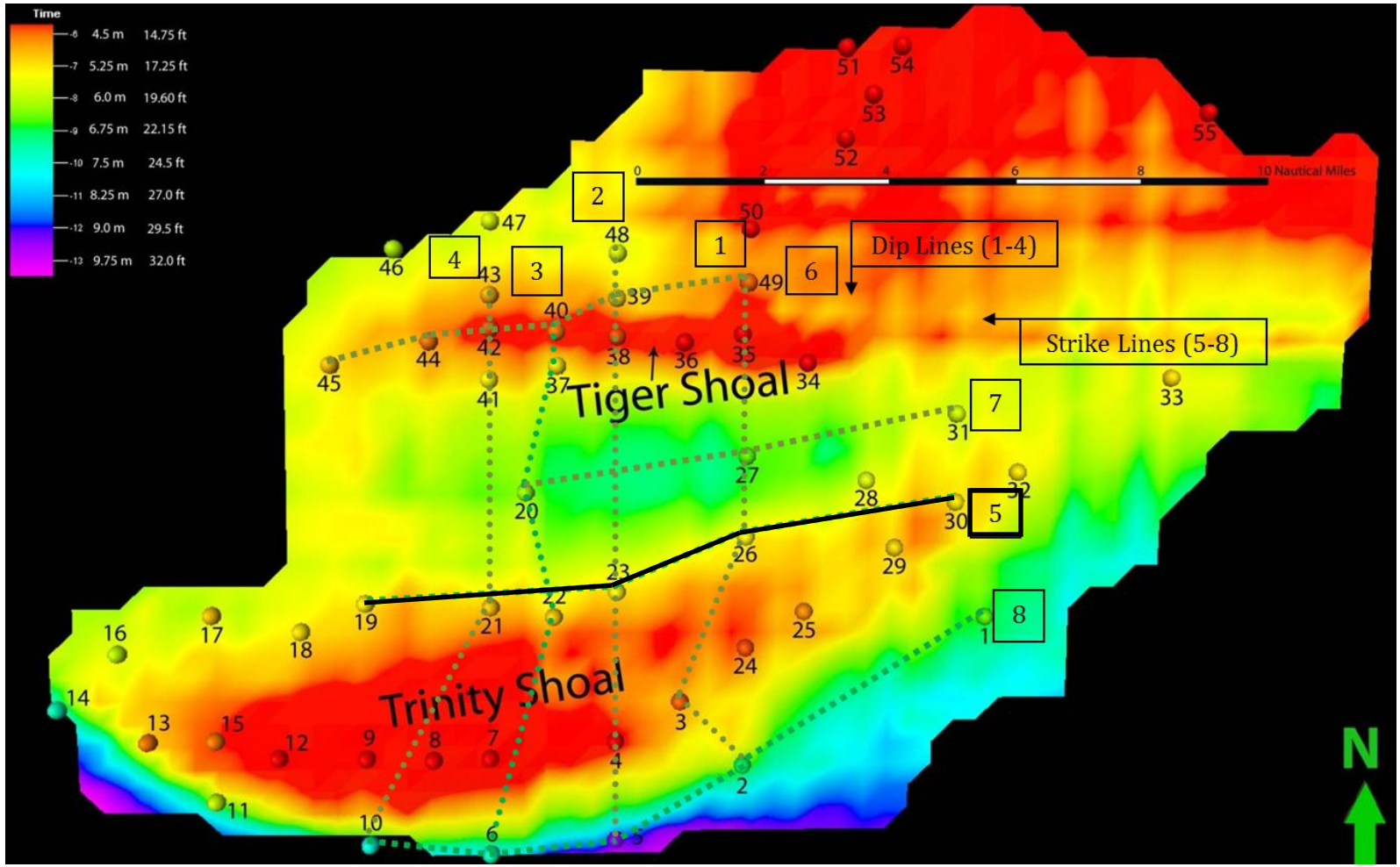


Line 4 Cont.
N>S



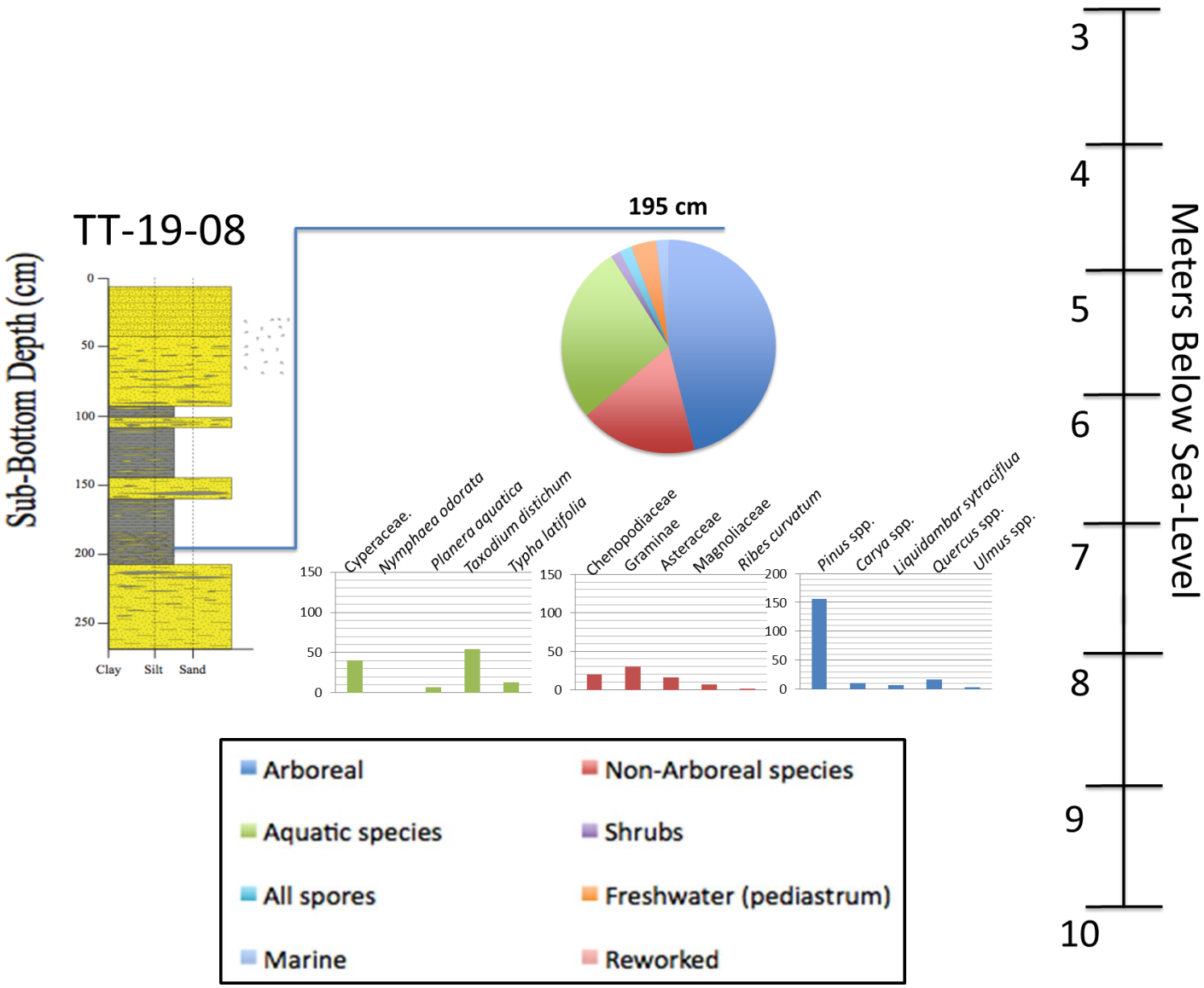
Line 4 Cont.
N>S



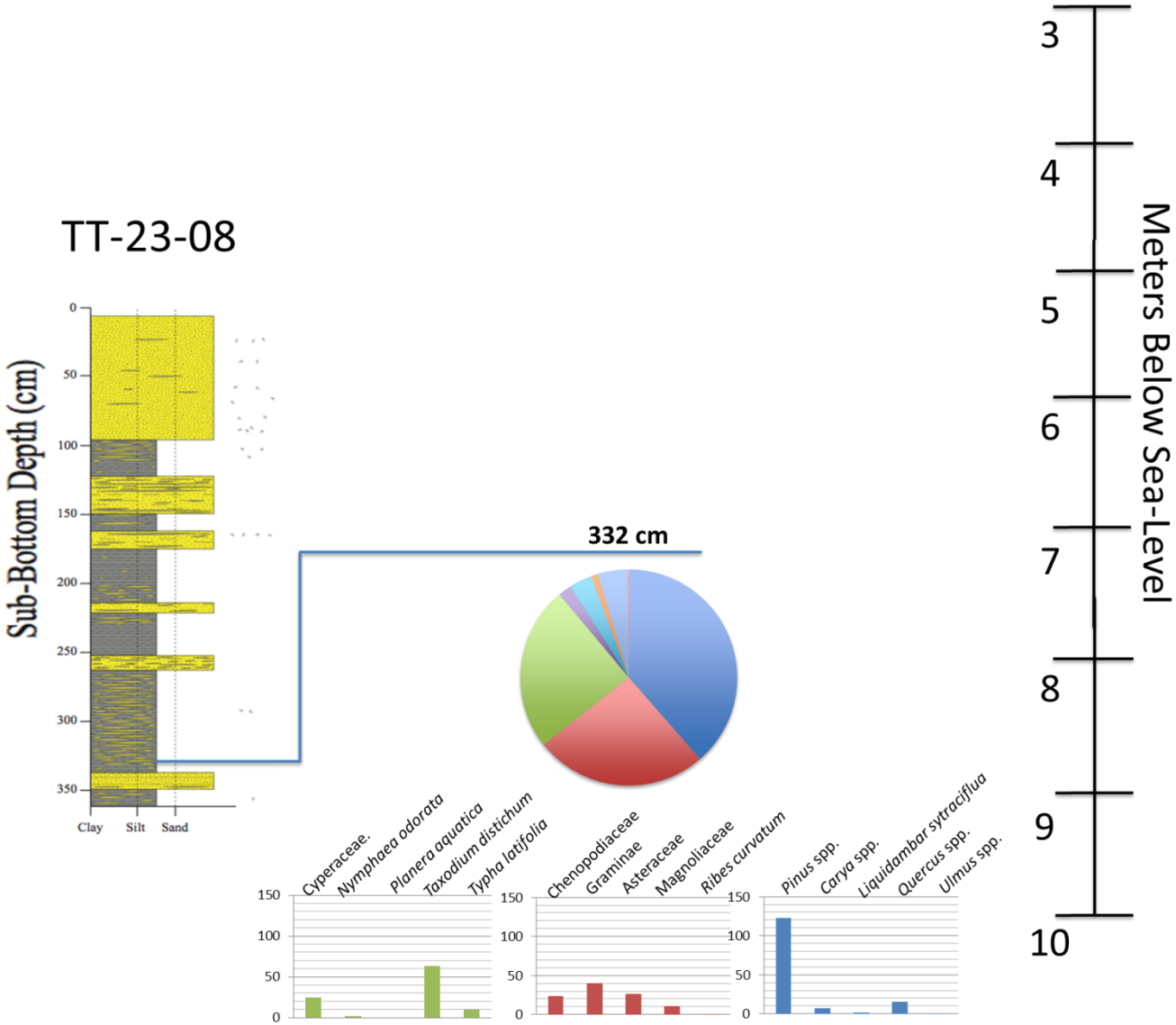

Time
-6 4.5 m 14.75 ft
-7 5.25 m 17.25 ft
-8 6.0 m 19.60 ft
-9 6.75 m 22.15 ft
-10 7.5 m 24.5 ft
-11 8.25 m 27.0 ft
-12 9.0 m 29.5 ft
-13 9.75 m 32.0 ft
0 2 4 6 8 10 Nautical Miles
Dip Lines (1-4)
Strike Lines (5-8)
Tiger Shoal
Trinity Shoal
N

Map of Line 5

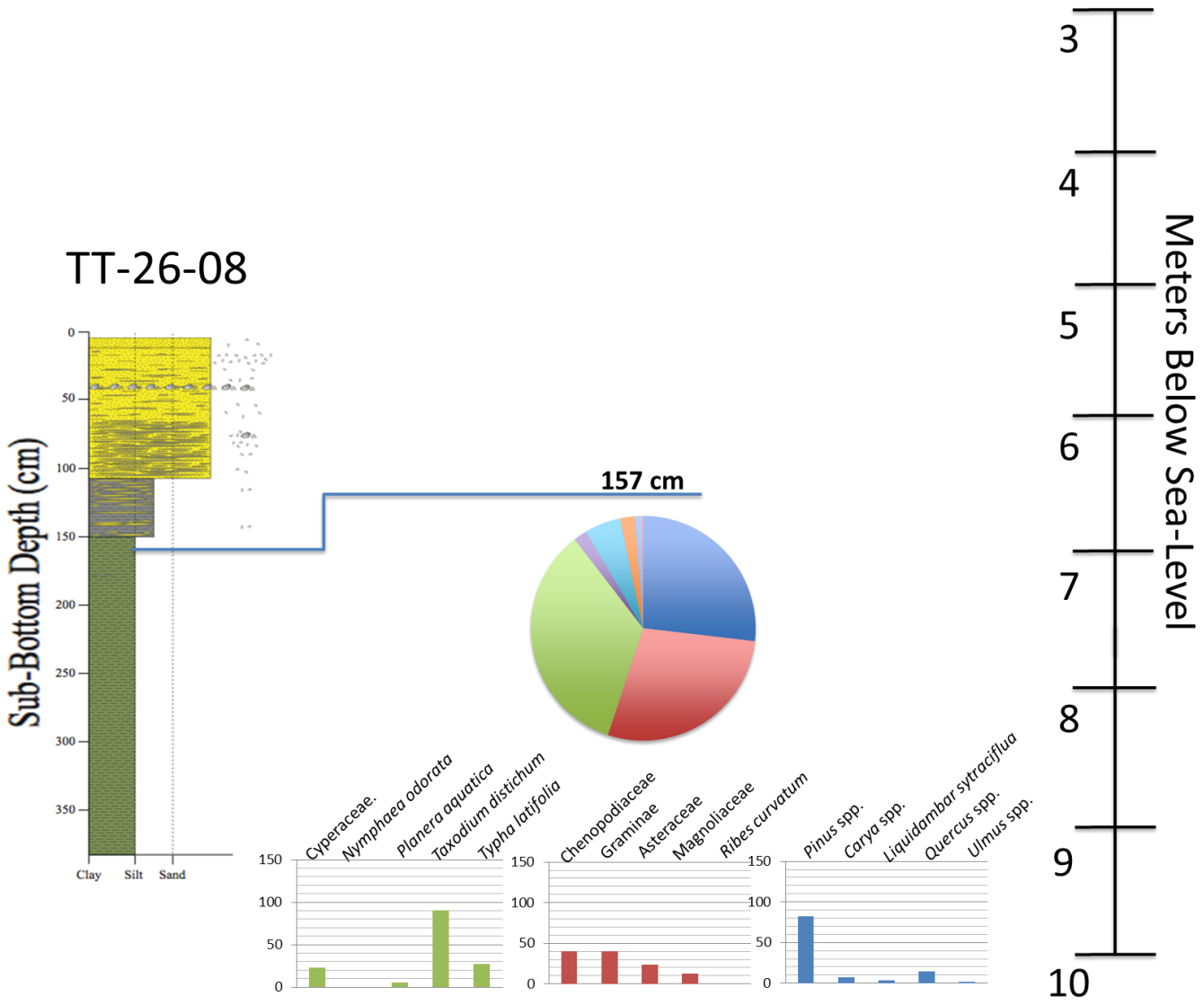
Line 5
W>E


TT-19-08
195 cm
Sub-Bottom Depth (cm)
0
50
100
150
200
250
Clay
Silt
Sand
Cyperaceae.
Nymphaea odorata
Planera aquatica
Taxodium distichum
Typha latifolia
Chenopodiaceae
Graminae
Asteraceae
Magnoliaceae
Ribes curvatum
Pinus spp.
Carya spp.
Liquidambar sytraciflua
Quercus spp.
Ulmus spp.
Arboreal
Non-Arboreal species
Aquatic species
Shrubs
All spores
Freshwater (pediastrum)
Marine
Reworked
Meters Below Sea-Level
3
4
5
6
7
8
9
10

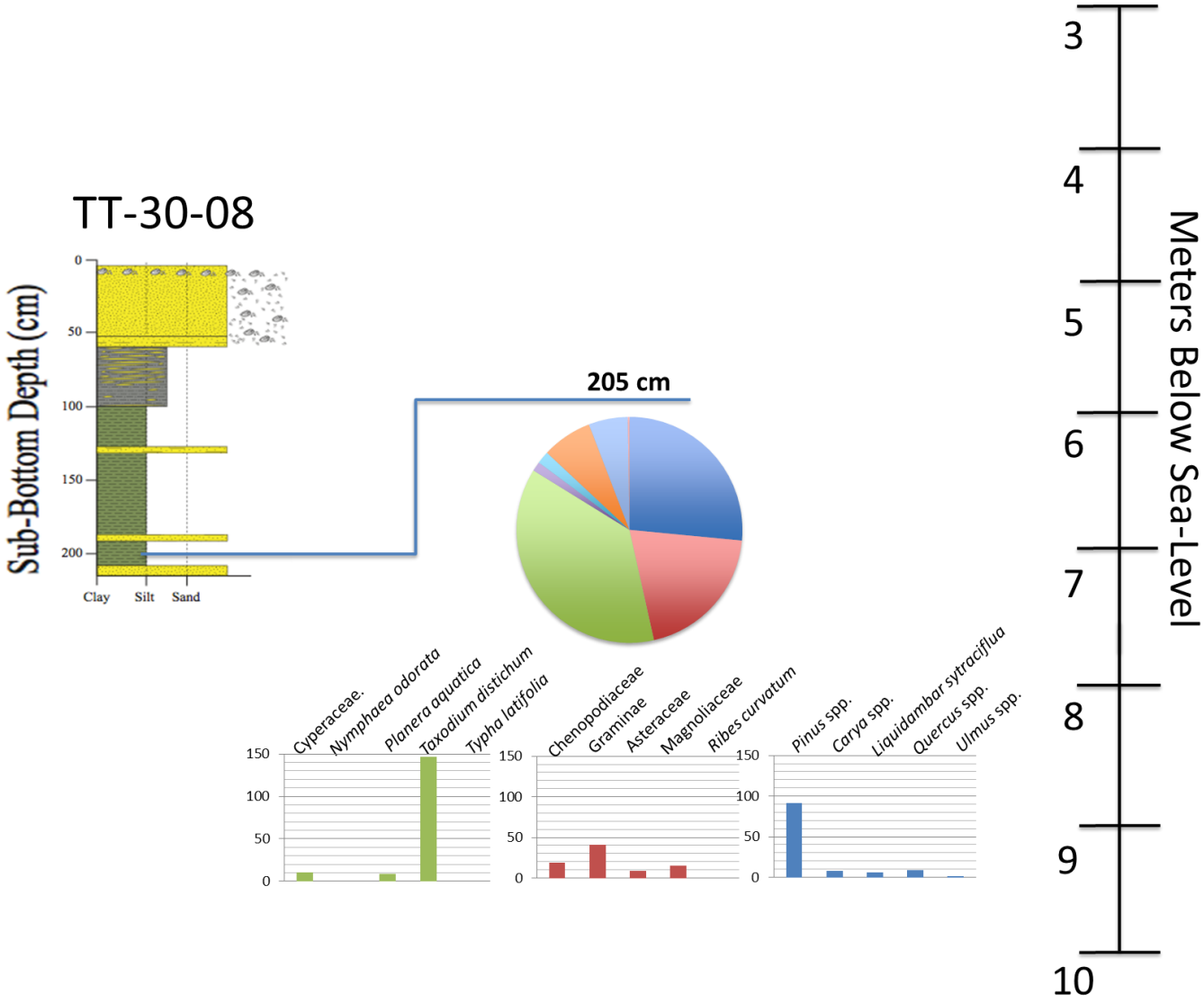
Line 5 Cont.
W>E



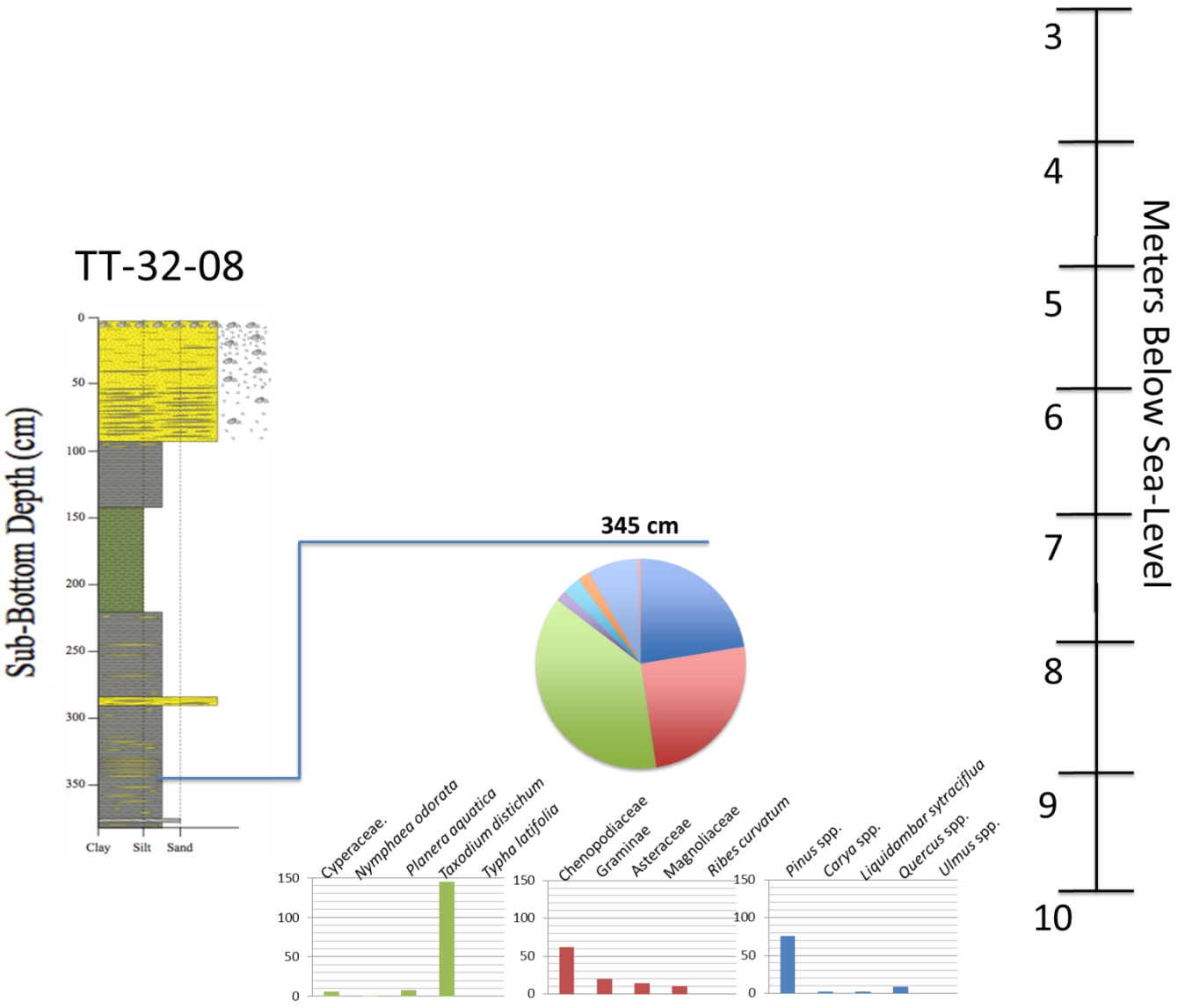
Line 5 Cont.
W>E

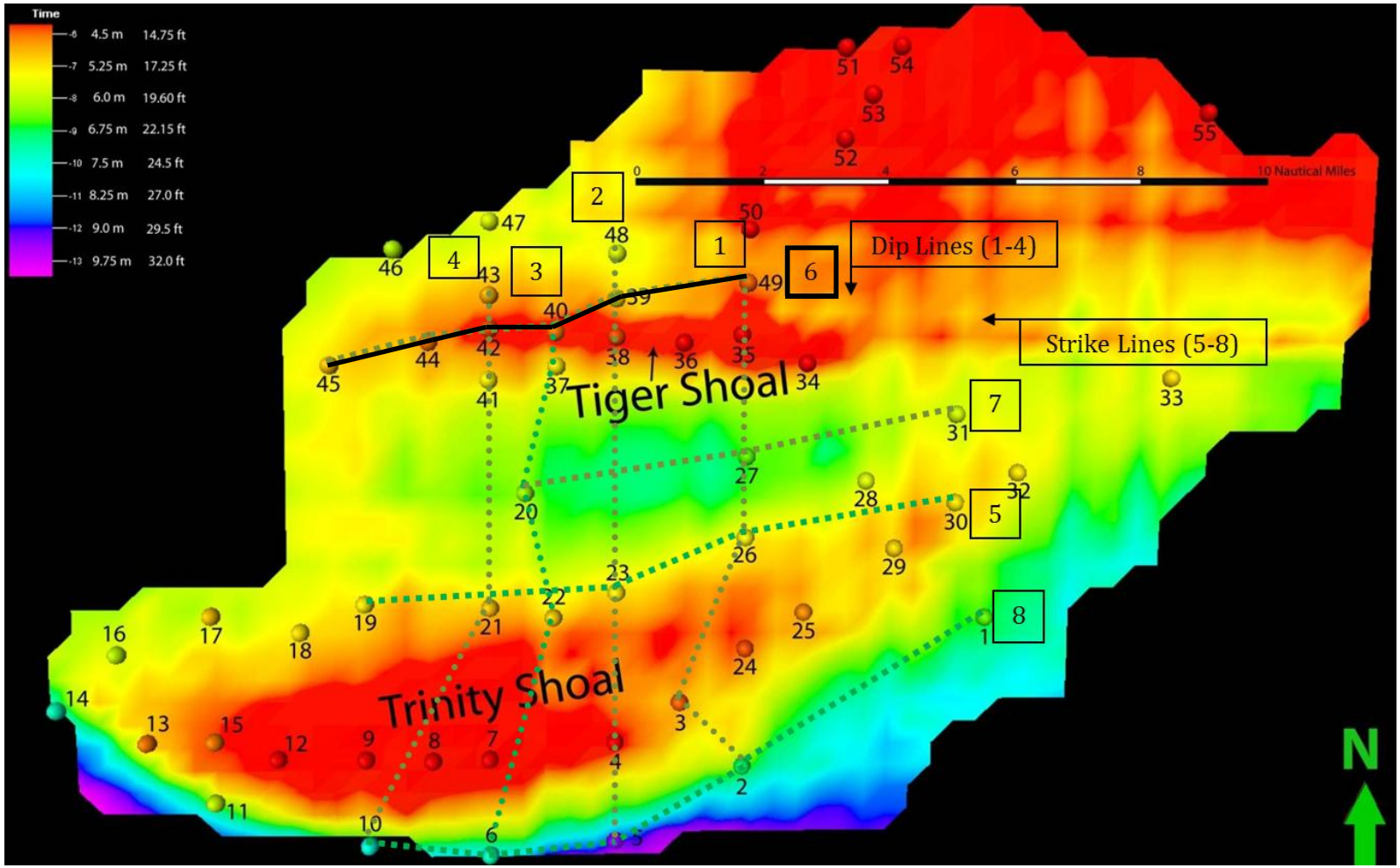


Line 5 Cont.
W>E



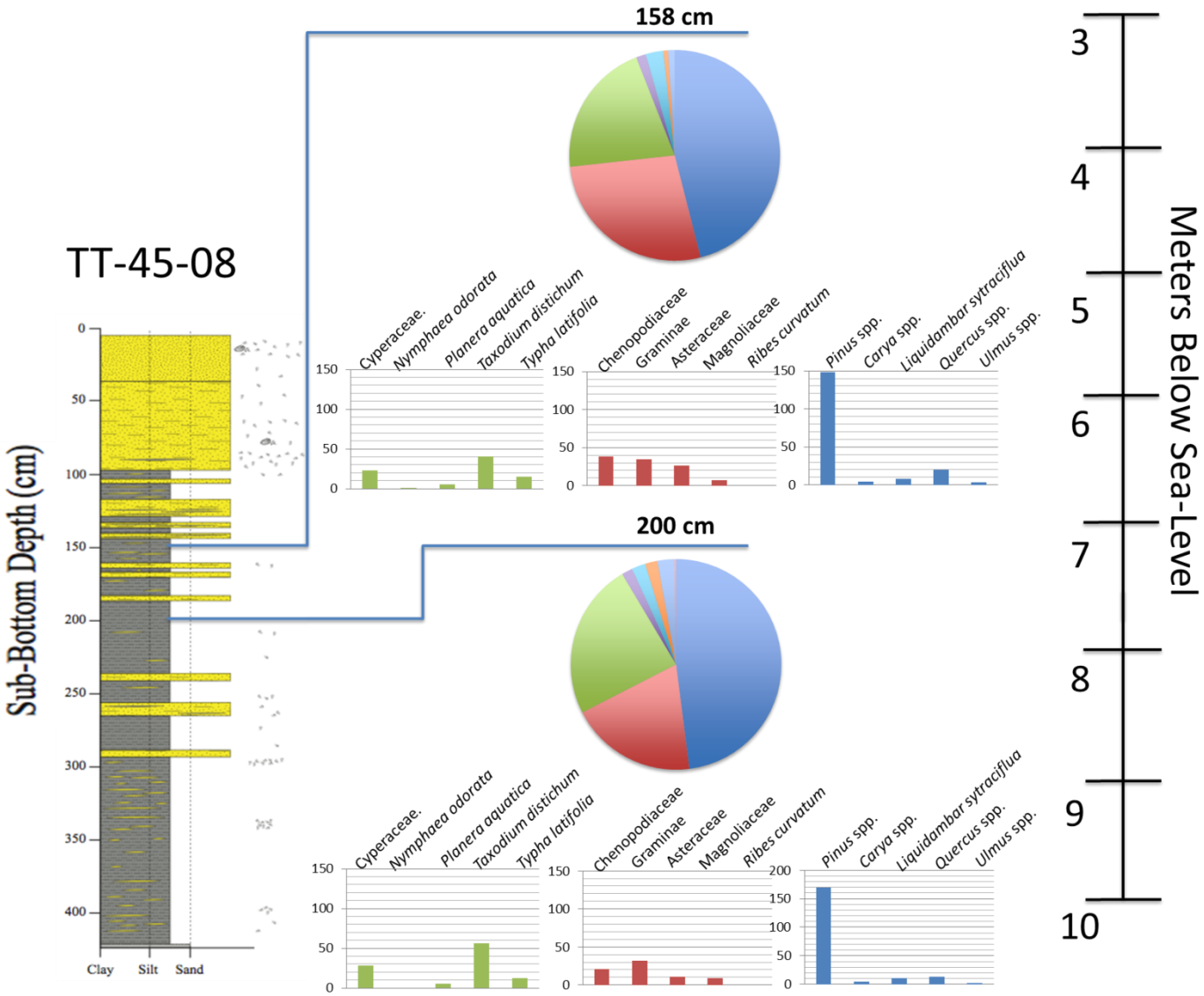
Line 5 Cont.
W>E



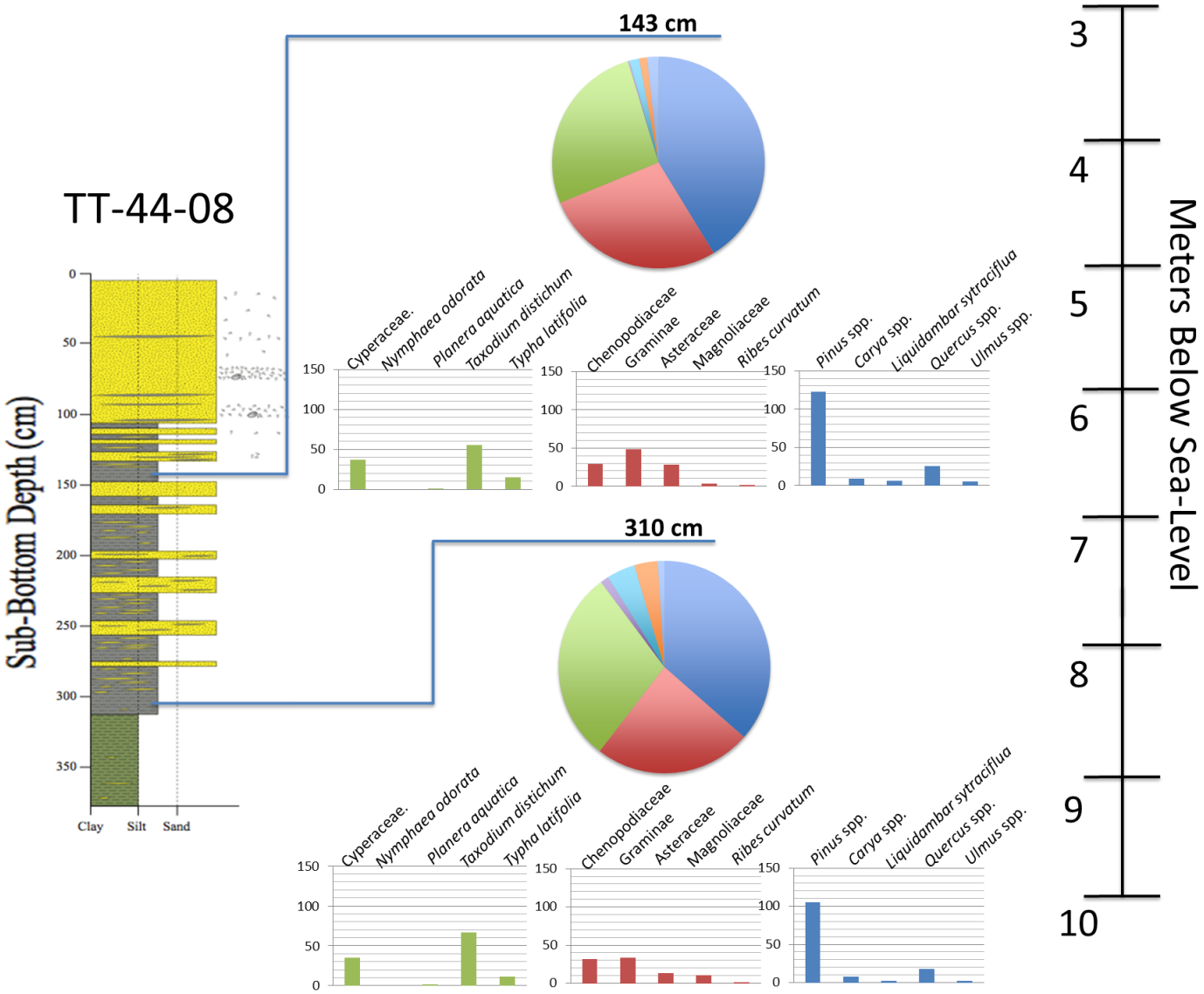

Time
-6 4.5 m 14.75 ft
-7 5.25 m 17.25 ft
-8 6.0 m 19.60 ft
-9 6.75 m 22.15 ft
-10 7.5 m 24.5 ft
-11 8.25 m 27.0 ft
-12 9.0 m 29.5 ft
-13 9.75 m 32.0 ft
0 2 4 6 8 10 Nautical Miles
Dip Lines (1-4)
Strike Lines (5-8)
Tiger Shoal
Trinity Shoal
N

Map of Line 6

Line 6
W>E


158 cm
200 cm
TT-45-08
Sub-Bottom Depth (cm)
0
50
100
150
200
250
300
350
400
Clay
Silt
Sand
Cyperaceae.
Nymphaea odorata
Planera aquatica
Taxodium distichum
Typha latifolia
Chenopodiaceae
Graminae
Asteraceae
Magnoliaceae
Ribes curvatum
Pinus spp.
Carya spp.
Liquidambar sytraciflua
Quercus spp.
Ulmus spp.
150
100
50
0
200
3
4
5
6
7
8
9
10
Meters Below Sea-Level

Line 6 Cont.
W>E



Line 6 Cont.
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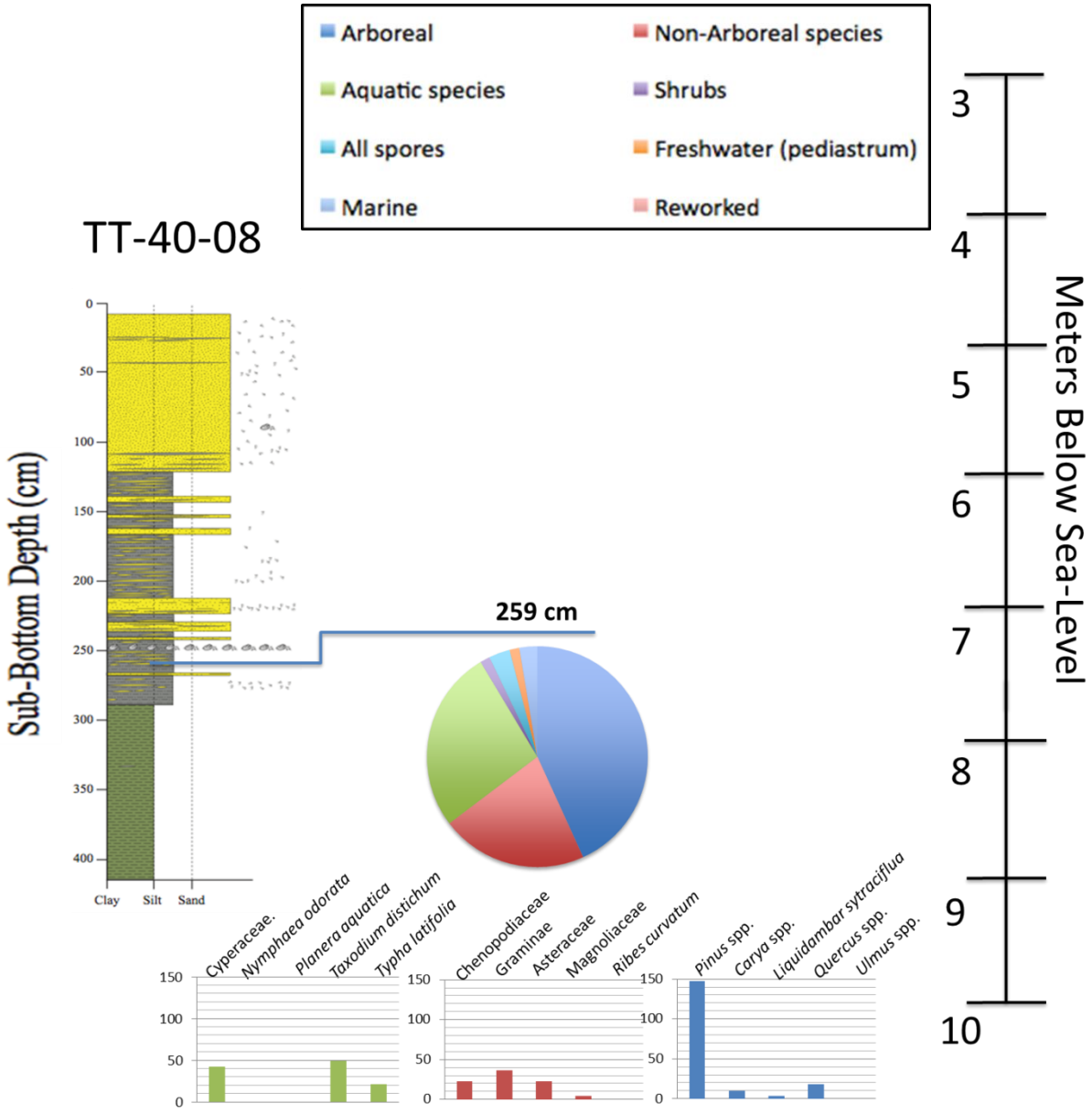
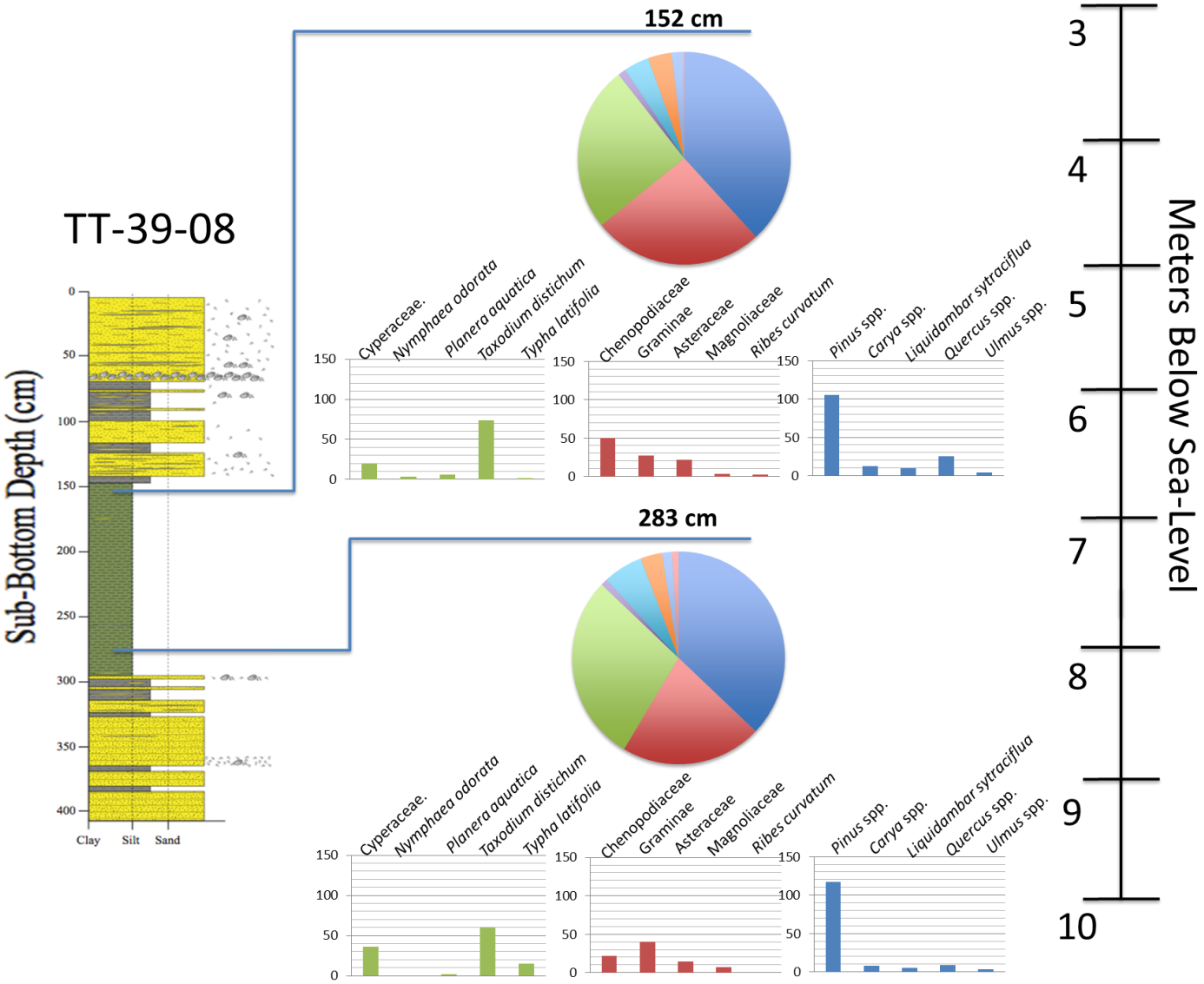
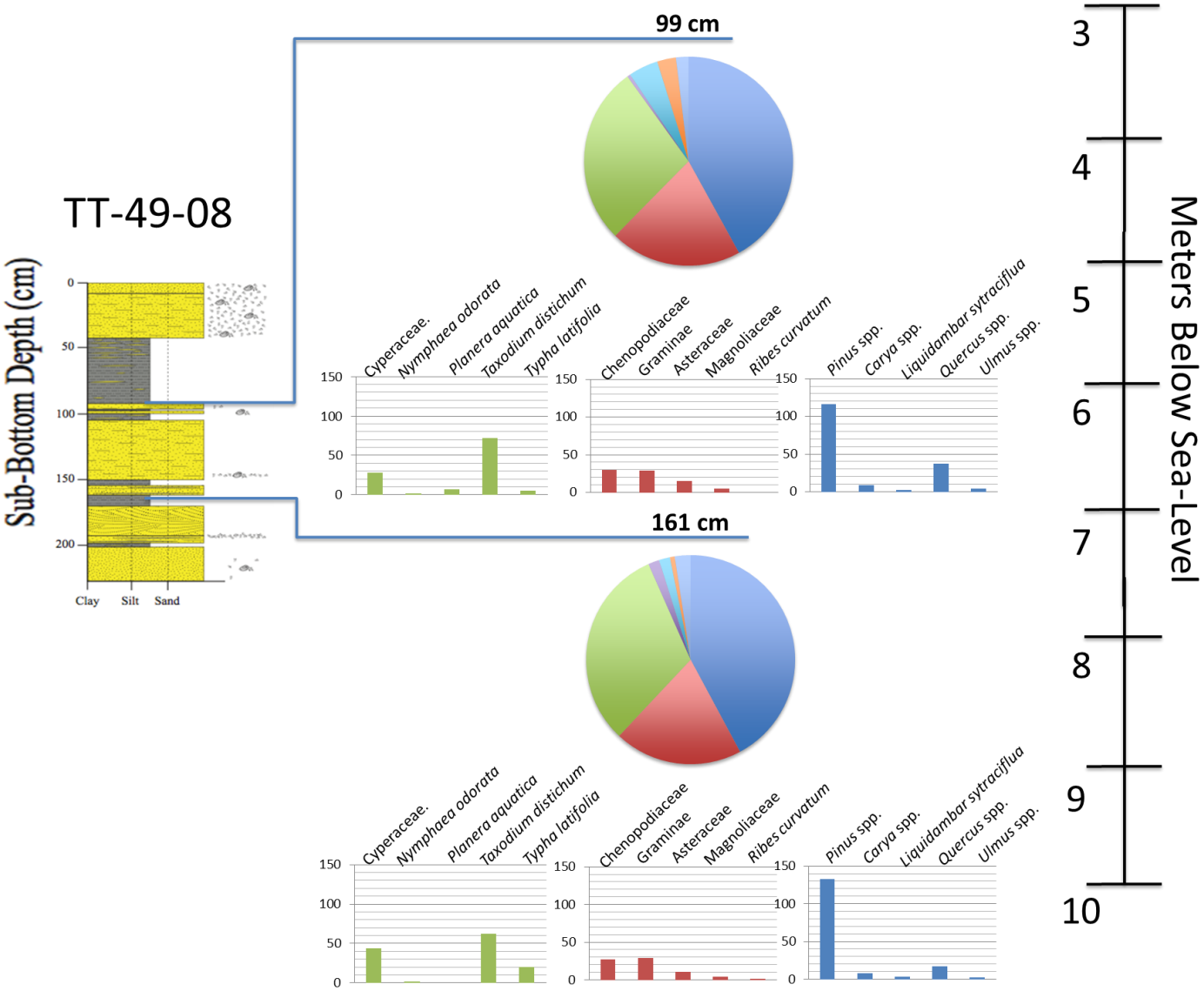
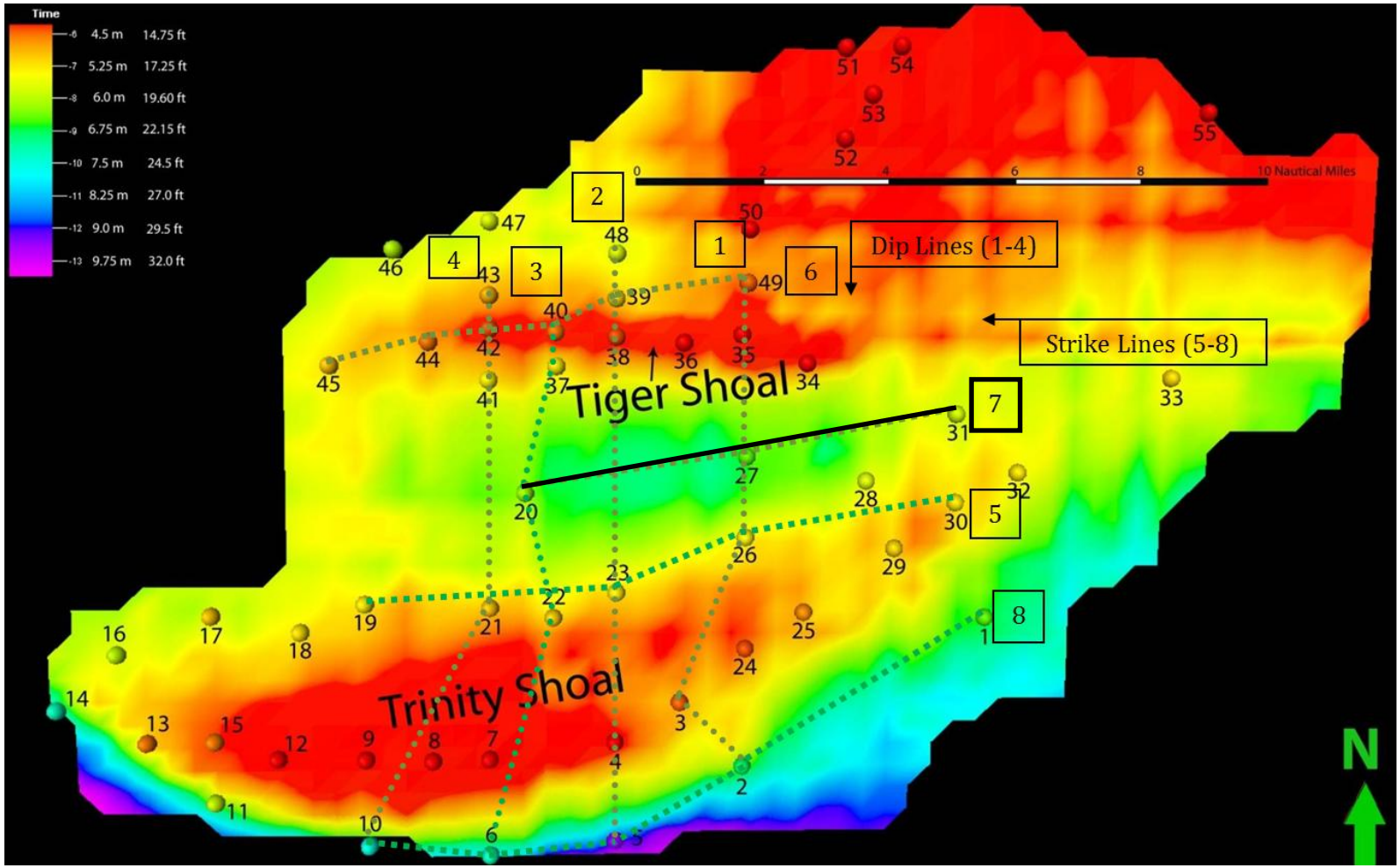


Line 6 Cont.
W>E



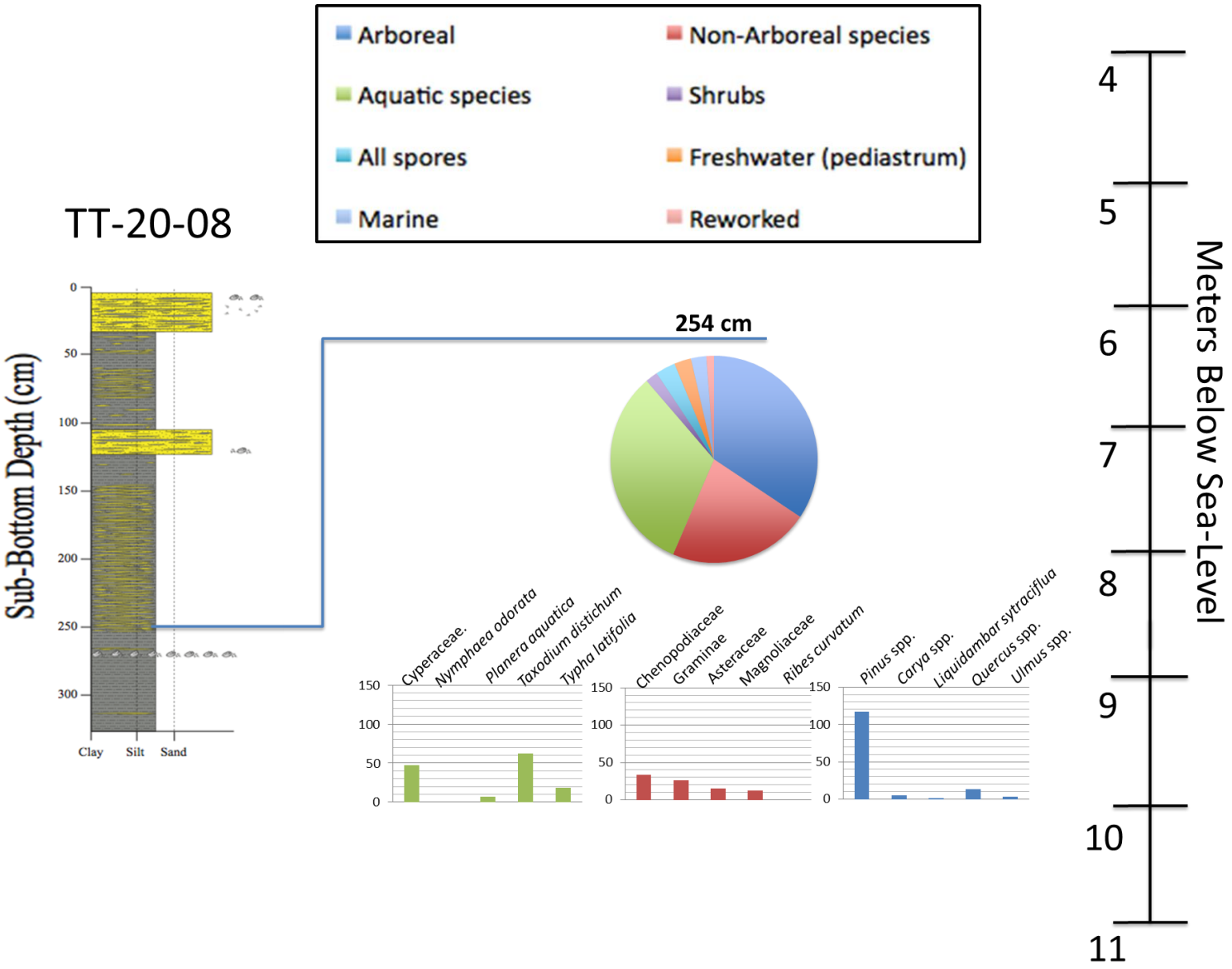
Line 6 Cont.
W>E



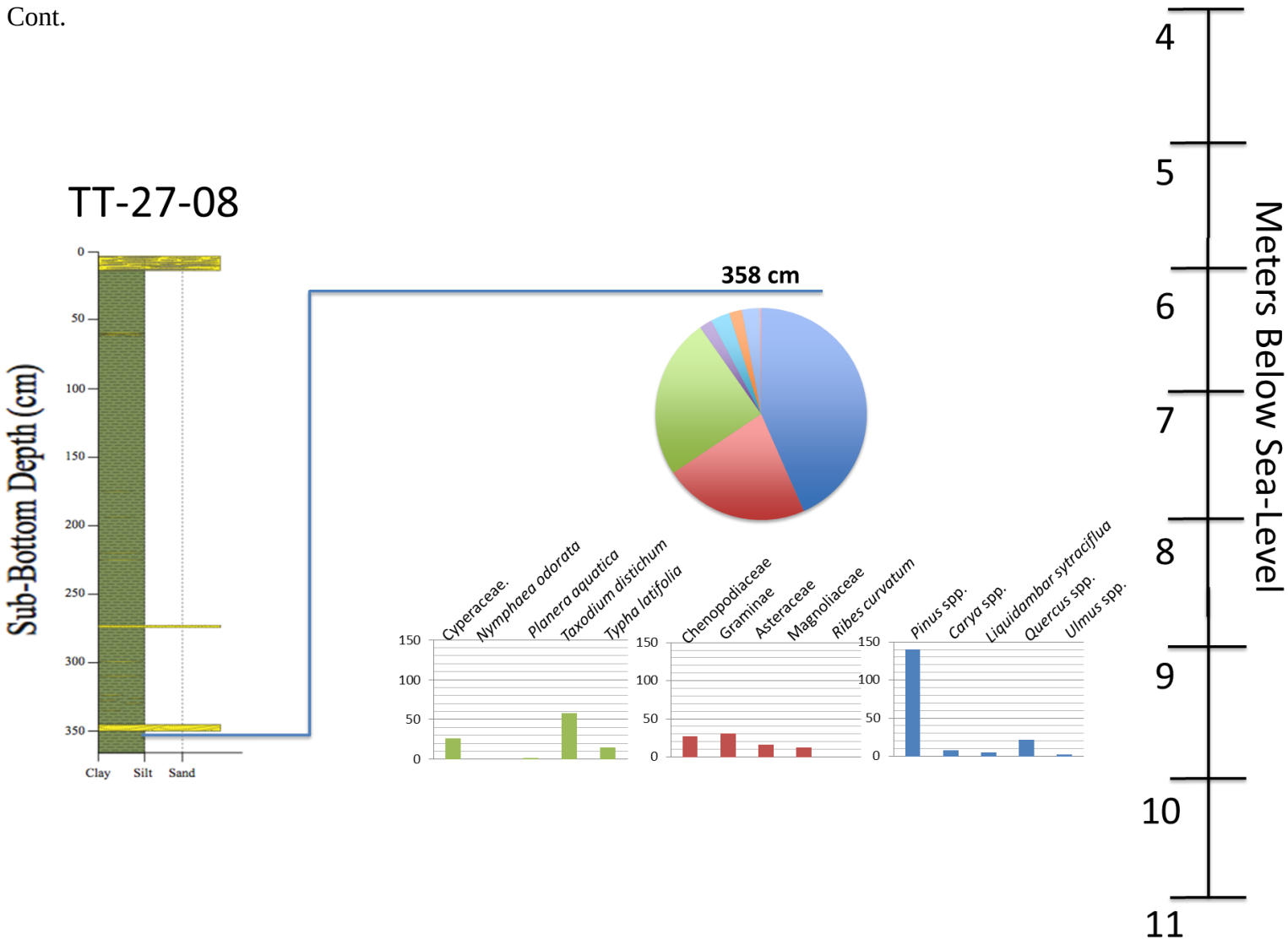

Time
-6 4.5 m 14.75 ft
-7 5.25 m 17.25 ft
-8 6.0 m 19.60 ft
-9 6.75 m 22.15 ft
-10 7.5 m 24.5 ft
-11 8.25 m 27.0 ft
-12 9.0 m 29.5 ft
-13 9.75 m 32.0 ft
0 2 4 6 8 10 Nautical Miles
Dip Lines (1-4)
Strike Lines (5-8)
Tiger Shoal
Trinity Shoal
N

Map of Line7

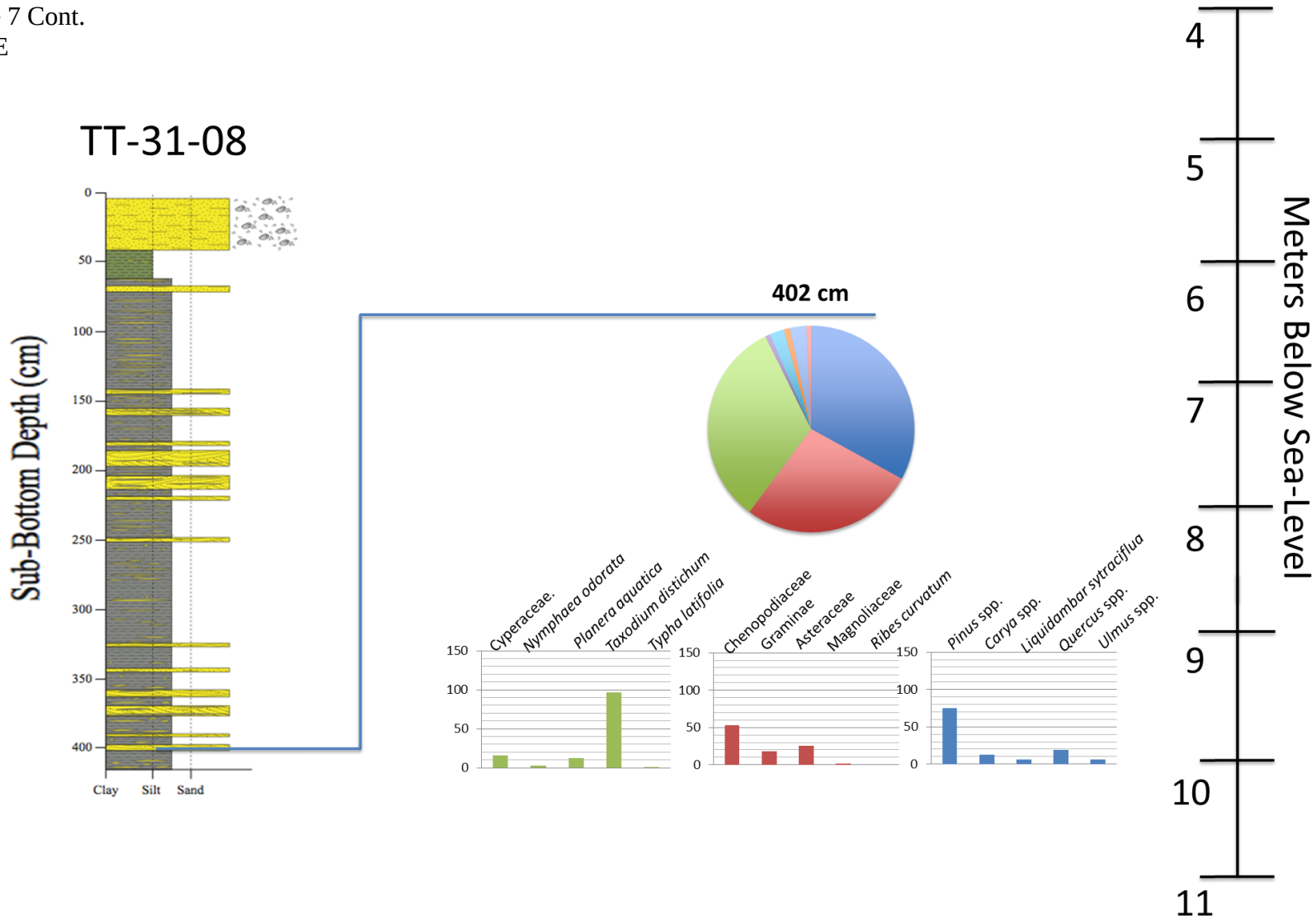
Line 7
W>E

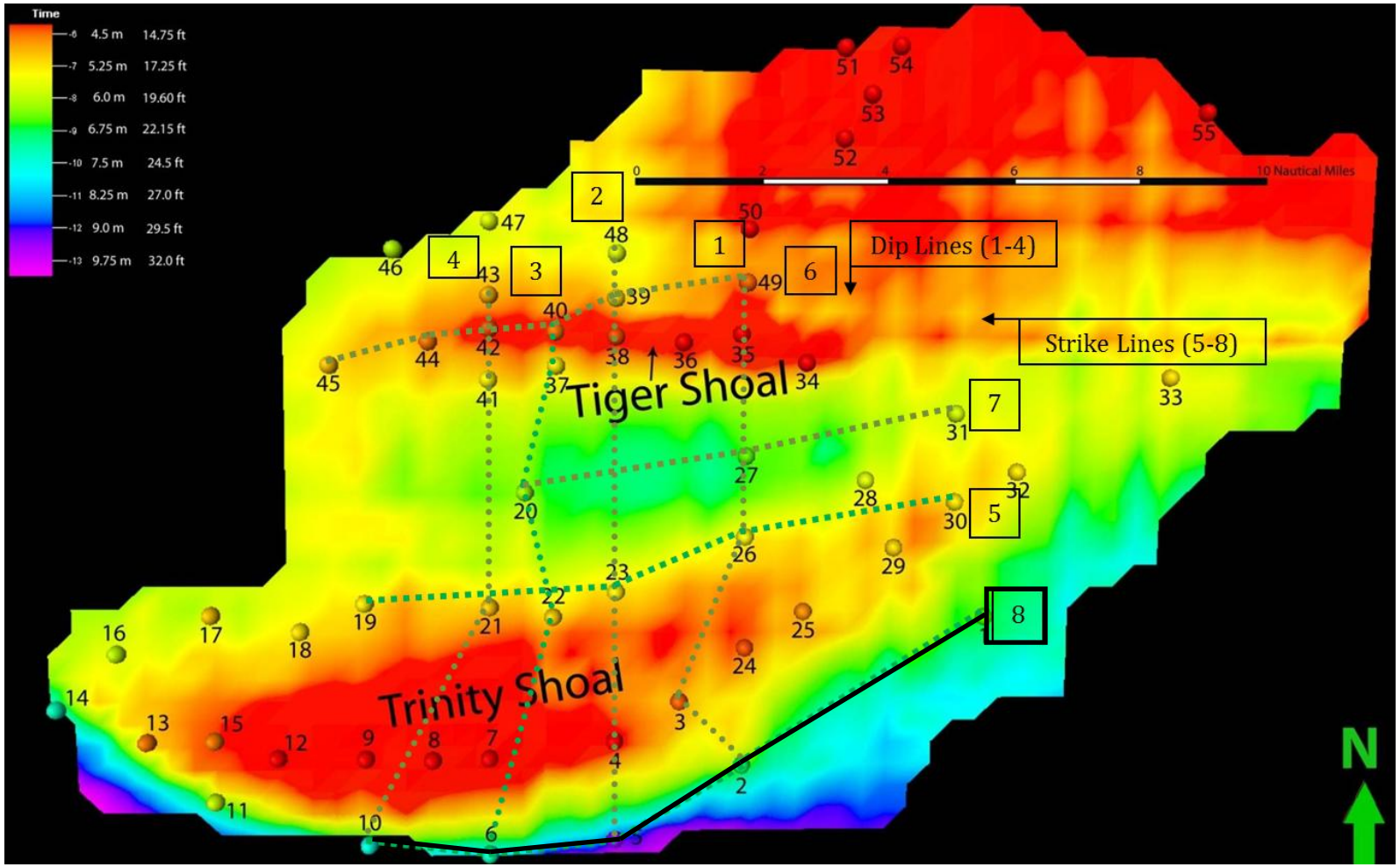

Arboreal
Non-Arboreal species
Aquatic species
Shrubs
All spores
Freshwater (pediastrum)
Marine
Reworked
TT-20-08
Sub-Bottom Depth (cm)
0
50
100
150
200
250
300
Clay
Silt
Sand
254 cm
Cyperaceae.
Nymphaea odorata
Planera aquatica
Taxodium distichum
Typha latifolia
Chenopodiaceae
Graminae
Asteraceae
Magnoliaceae
Ribes curvatum
Pinus spp.
Carya spp.
Liquidambar sytraciflua
Quercus spp.
Ulmus spp.
150
100
50
0
4
5
6
7
8
9
10
11
Meters Below Sea-Level

Line 7 Cont.
W>E



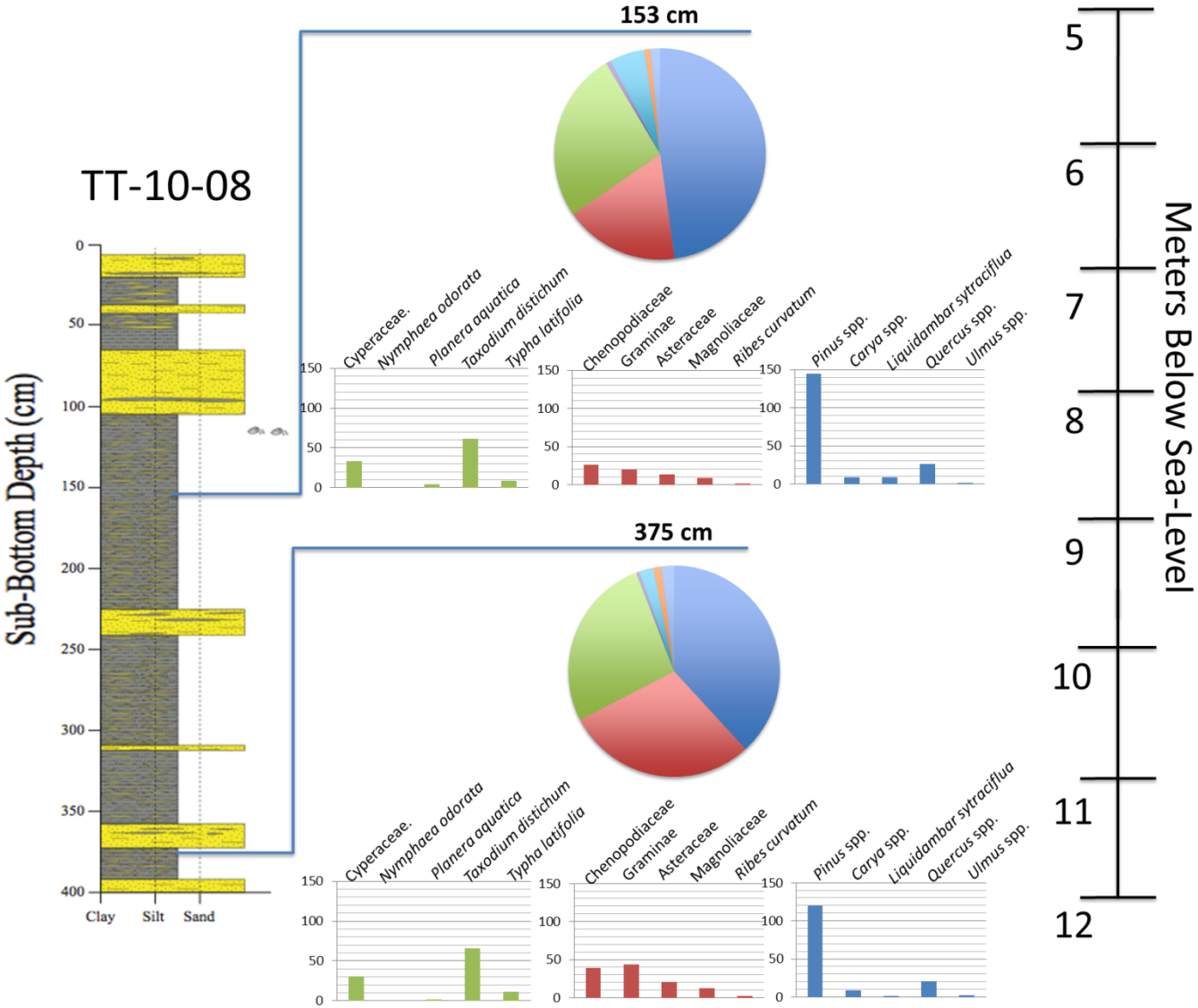
Line 7 Cont.
W>E



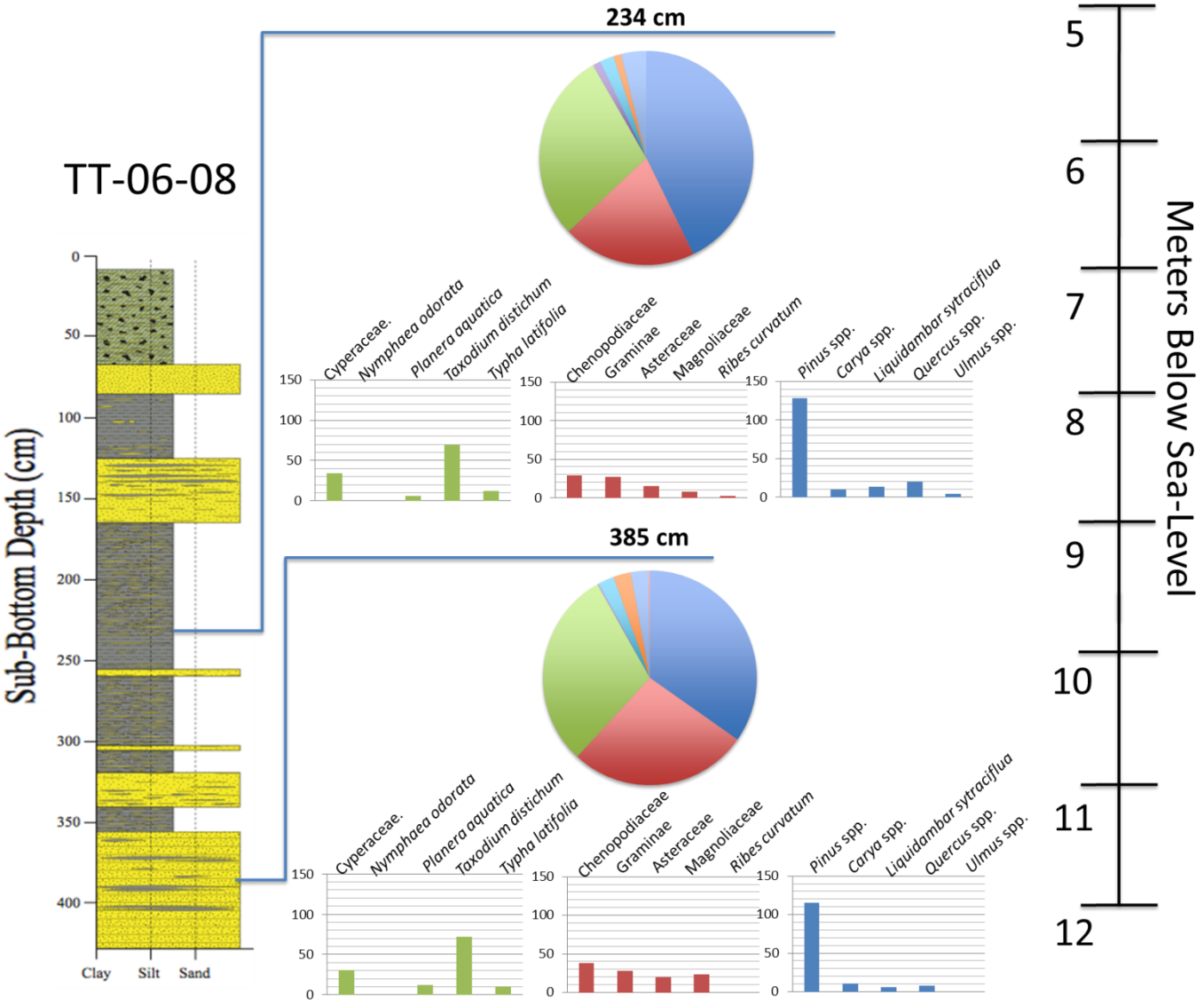

Time
-6 4.5 m 14.75 ft
-7 5.25 m 17.25 ft
-8 6.0 m 19.60 ft
-9 6.75 m 22.15 ft
-10 7.5 m 24.5 ft
-11 8.25 m 27.0 ft
-12 9.0 m 29.5 ft
-13 9.75 m 32.0 ft
0 2 4 6 8 10 Nautical Miles
Dip Lines (1-4)
Strike Lines (5-8)
Tiger Shoal
Trinity Shoal
N

Map of Line 8

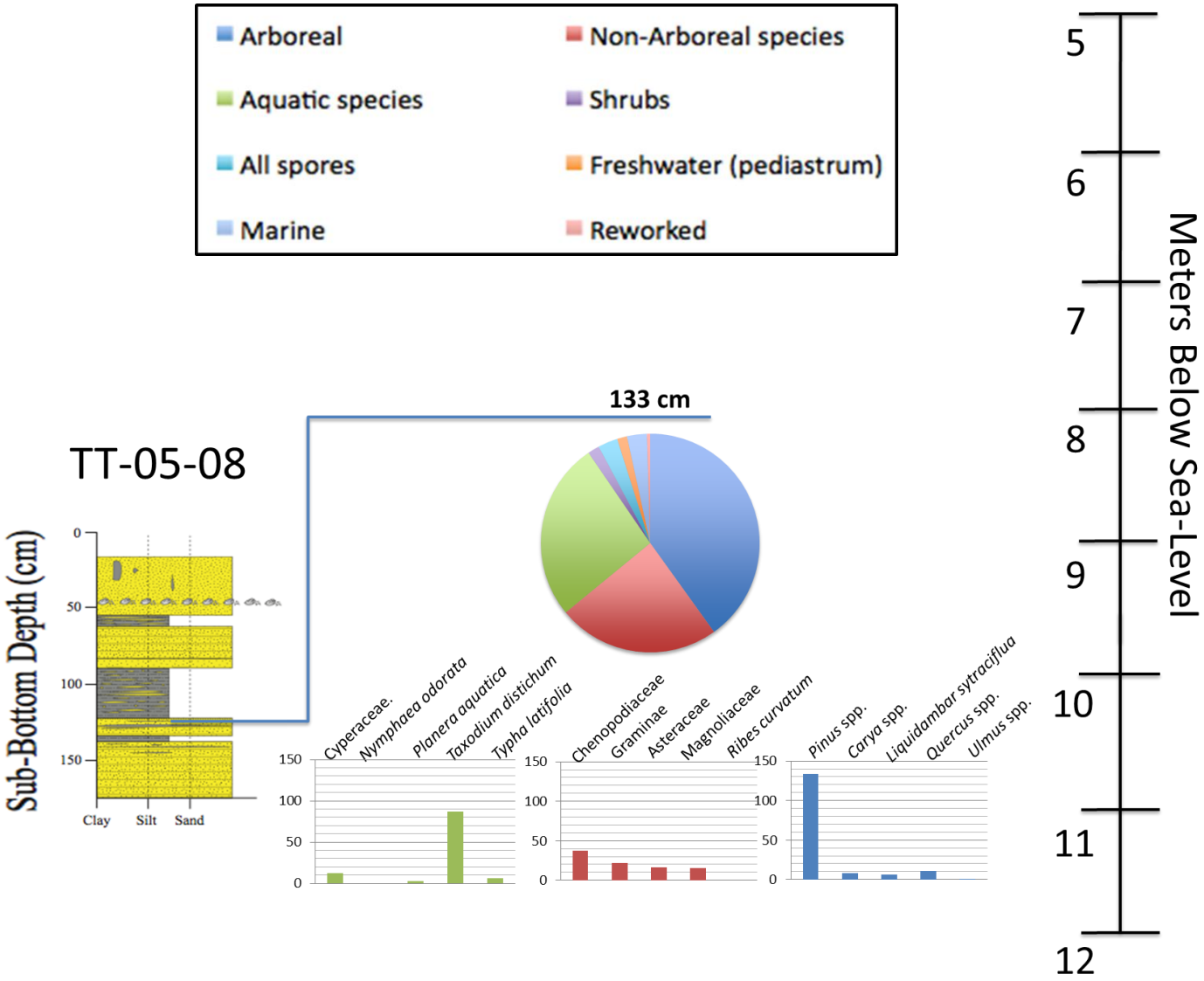
Line 8
W>E


TT-10-08
Sub-Bottom Depth (cm)
0
50
100
150
200
250
300
350
400
Clay
Silt
Sand
153 cm
375 cm
Cyperaceae.
Nymphaea odorata
Planera aquatica
Taxodium distichum
Typha latifolia
Chenopodiaceae
Graminae
Asteraceae
Magnoliaceae
Ribes curvatum
Pinus spp.
Carya spp.
Liquidambar sytraciflua
Quercus spp.
Ulmus spp.
150
100
50
0
5
6
7
8
9
10
11
12
Meters Below Sea-Level

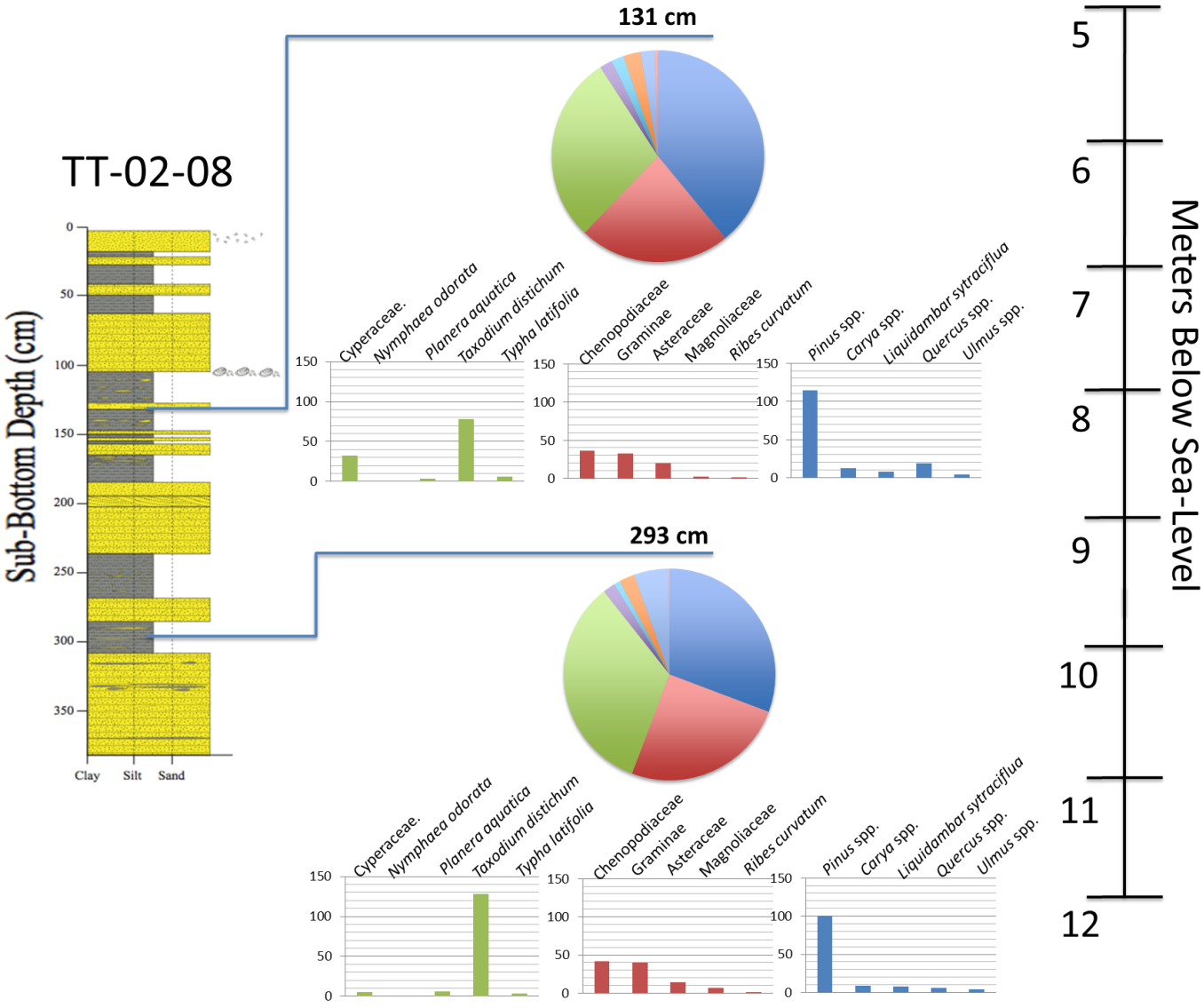
Line 8 Cont.
W>E



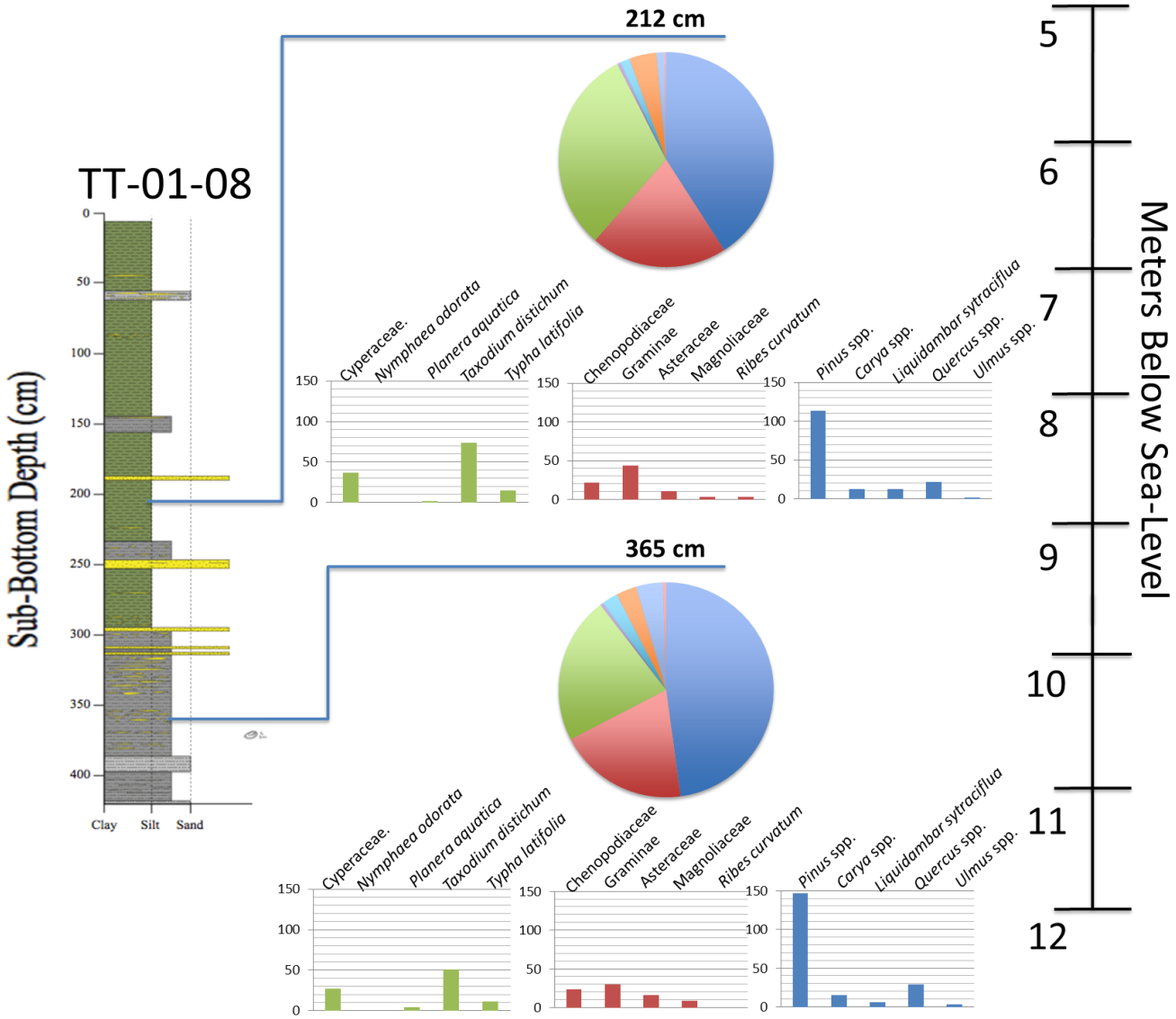
Line 8 Cont.
W>E



Line 7 Cont.
W>E



Line 7 Cont.
W>E



VITA

Russell Ryan Crouch was born in San Antonio, Texas, in 1984. He moved to Corpus Christi, Texas, in 2005 and attended Texas A & M Corpus Christi where he graduated with a Bachelor of Science degree in geology in August of 2008. Russell has always been interested in nature and being outside in general.

In the summer of 2009 he was awarded an internship as a geologist with EOG Resources in Corpus Christi where he was offered a full-time position as an operations geologist, which he accepted. Russell will graduate with a Master of Science degree in geology in December 2010.